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Report No. ZH-150
Hydrodynamics

STUDY OF LOADS AND MOTIONS OF TWO TYPES OF GROUND EFFECT MACHINES

by

S. T. Uyeda

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GENERAL DYNAMICS/CONVAIR

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Approved by

H. E. Brooke

GENERAL DYNAMICS/CONVAIR

FOREWORD

This report presents the experimental results of overwater loads and motions evaluations of two ground effect machine (GEM) configurations. The investigations were conducted for the U. S. Navy Department, Bureau of Ships, under Contract NObs 4360. The tests were conducted using dynamically similar models at the General Dynamics/Convair Hydrodynamics Laboratory.

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SYMBOLS

C	Nozzle length measured at centerline of nozzle exit, (feet)
D	Total drag, (pounds)
f	Frequency
fe	Frequency of wave encounter
fn	Undamped natural frequency in heave
fn_p	Undamped natural frequency in pitch
f_p	Forcing frequency of peak amplitude
g	Local acceleration of gravity, (feet per second squared)
G	Nozzle width, (feet)
h_o	Steady state operating height over hard surface measured to the lower edge of nozzle, (feet)
h_w	Wave height measured from trough to crest, (feet)
J	Jet momentum, (pounds)
K	Spring constant, (pounds per foot)
L	Craft length, (feet)
L	Total lift, (pounds)
L_B	Buoyant lift, (pounds)
M	Pitching moment, (pound-feet)
Δp	Base pressure, (pounds per square foot)
q	Dynamic pressure, (pounds per square foot)
S	Base area, (square feet) (plan area enclosed by outer edge of nozzle exit)
W	Craft weight, (pounds)
Θ	Pitch angle, (degrees)
Θ_w	Maximum wave angle, (degrees)
λ	Wave length, (feet)
ζ	Damping ratio

SUMMARY

~~This report presents the~~ results are presented for ~~of the~~ dynamically similar experimental model evaluations of the over water loads and motions of two ground effect machine configurations.

Two basic configurations were tested: ~~during the program.~~

(1) The DTMB Annular Jet Configurations; and

(2) The Bureau of Ships Side Skeg Configurations.

The program consisted primarily of ~~the determination of~~ determining the heaving and pitching motions incurred during normal operation in smooth water and in various regular wave conditions. Also, the rigid body load factors resulting from sudden power failure during maximum cruising condition in waves were determined. to p. 5

The scope of the program was essentially to investigate the general GEM parameters and no detailed study of specific problems was made. A list of possible problem areas and recommendations for further study are presented.

The following specific investigations were conducted with both GEM configurations:

1. Pitching and heaving motions at several velocities up to cruising velocity in smooth water.
2. Pitching and heaving motions at several velocities up to cruising velocity in sinusoidal waves.
3. Pitching and heaving motions while floating and hovering over sinusoidal waves.
4. Vertical accelerations incurred during normal operation over waves.
5. Rigid body load factors incurred during power failure in waves.
6. Measurement of drag forces during operations in smooth water.

7. The effect of increased weight (base pressure), for constant hover height, on the pitching and heaving motions of the GEM.

In addition to the above tests conducted with both GEM configurations, several specialized investigations were conducted with the individual models.

Tests were conducted with the DTMB annular jet configuration to determine:

1. The heave response of the vehicle in waves with one degree of freedom.
2. The pitch response of the vehicle in waves with one degree of freedom.
3. The water impact velocity and acceleration produced by vertical drops (power on and power off).

Additional tests were conducted with the BuShips side skeg model incorporating several bottom configurations to determine the heaving and pitching motions during operation in smooth water and in waves.

Motion picture records were obtained for both configurations while operating over smooth water and in waves. Motion picture records for the power failure during cruising were also obtained. Selected portions of these motion pictures have been combined to form a supplement to this report (General Dynamics/ Convair, Film Report 1058).

The specialized tests with the DTMB configuration were conducted to provide vital input data for a companion program performed on an analog computer. This program, conducted for the U. S. Navy Department, Bureau of Naval Weapons, is described in General Dynamics/Convair Report ZP-346. This report compares the analytically determined loads and motions of the DTMB configuration with the experimental data of this report.

INTRODUCTION

Ground effect machines (GEM's) hold forth promise of fulfilling a great variety of functions in future military operations. Under certain specialized conditions they present a means for the transportation of personnel, supplies, troops, and cargo with greater speed and safety than other vehicles currently available or planned for future development. Perhaps of even more importance, they provide a means of transportation over difficult terrain where no form of travel currently exists.

Many of the important uses envisioned for GEM vehicles involve operation over water. In order to better understand the general over-water behavior of these machines as an aid to the development of practical and useful vehicles, it is vital that the effect of certain design parameters, limiting water surface conditions, and vehicle structural requirements be determined.

The U. S. Navy Department, in pursuit of this information, has entered into a comprehensive program of GEM research and vehicle development.

The experimental model investigations reported herein, and sponsored by the Bureau of Ships, represent a portion of the over-all Navy research program. The purpose of these model investigations was to evaluate and compare the motions and loads incurred by two specific GEM configurations during operation over water. The two configurations investigated were the DTMB Annular Jet design and the BuShips Side Skeg design.

RESULTS

The subject model testing program with the two GEM configurations has shown that the vehicles are subject to heaving and pitching motions and accelerations when operating over waves. The amplitude and frequency of these motions and accelerations are dependent upon a number of design and operating parameters.

In general, the present over-water GEM vehicle tests, in sinusoidal wave conditions, indicate the following:

1. The peak response amplitude occurs at fe/fn (frequency of encounter/undamped natural frequency) of less than 1.0 and is a function of the damping ratio, (ζ).
2. The peak response amplitude in heave and pitch increases with the wave length to craft length ratio (λ/L).
3. The vertical accelerations increase with the wave length to craft length ratio (λ/L).

The following specific results were obtained for the two basic configurations:

<u>DTMB Annular Jet Configuration</u>

1. Maximum heave response amplitude ratios ($\Delta h/h_w$) varied from 1.10 to .40 as wave length to craft length ratios (λ/L) varied from 2.00 to .55 (see Figure 12).
2. Maximum pitch response amplitude ratios ($\Delta \Theta/\Theta_w$) varied from 2.50 to .40 as wave length to craft length ratios (λ/L) varied from 2.00 to .55 (see Figure 13).
3. The frequency ratio for the peak heave amplitude varied from 0.8 to 0.6 as the base pressure increased from 50.302 to 100.022 psf (Figure 17).

4. The frequency ratio for the peak pitch amplitude remained constant at .40 as base pressure increased (Figure 17).
5. Peak accelerations occurred at the critical heave frequency and were maximum for the longest wave length tested ($\lambda/L = 2.0$). The peak forward accelerations were of the order of 1.0 g. The peak c.g. accelerations were approximately .70 of a g (see Figures 18 and 20).
6. Power failure impact loads were measured and found to be of the order of 2.0 g's at 87.5 knots (Figure 24).
7. The maximum drag to weight ratio was .10 (Figure 27).
8. Aerodynamic lift coefficient (C_L) at zero angle of attack was 0.52.

BuShips Side Skeg Configuration with Knife-edged Skeg (Flat Bottom)

1. The maximum heave response ratios ($\triangle h/h_w$) varied from .60 to .30 as wave length to craft length ratios (λ/L) varied from 1.78 to .56 (see Figure 14).
2. Maximum pitch response amplitude ratios ($\triangle \Theta/\Theta_w$) varied from 2.20 to .80 as wave length to craft length ratios (λ/L) varied from 1.78 to .56 (Figure 15).
3. The frequency ratio of peak heave amplitude varied from 1.0 to .80 as the base pressure increased from 59.44 to 77.41 psf (Figure 17).

4. The frequency ratio of peak pitch amplitude was .58 and was independent of base pressure variation (Figure 17).
5. Peak accelerations occurred at the critical heave frequency at $\lambda/L = 2$. Maximum forward acceleration of 1.0 and c.g. accelerations of .85 were obtained (Figures 19 and 20).
6. Power failure impact loads of 2.0 g's were obtained at 87.5 knots (Figure 2).
7. The maximum drag to weight ratio (D/W) was .50 (Figure 27).
8. Incorporation of the concave bottom did not appreciably influence the loads and motions in speed ranges up to 100 knots.
9. The convex bottom was found to be unsuitable for operation over water.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

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Based upon the results of the tests described herein, it is concluded that GEM vehicles operating over waves are subject to critical heaving and pitching motions and accelerations. These motions and accelerations are of paramount importance to the feasibility of the GEM concept during over-water operation. The results ~~of the present tests have shown~~ indicate that much can be done to minimize the motions and loads of these vehicles. Valuable data ~~have been~~ were gained for the judicious selection of optimum design parameters. The tests ~~have~~ also indicated some of the major problem areas which will require further investigation ~~in order~~ to insure the safety, structural integrity, and comfort of GEM vehicles operating over waves.

It is believed that further experimental and analytical studies in the following areas are required:

1. Determine local bow and bottom water pressures and develop sound hydrodynamic theories for predicting pressures.
2. Investigate bow and bottom configurations that will minimize local water pressures and impact loads.
3. Determine a rational method for the design of bow and bottom panel structures to withstand the local and average water pressures.
4. Investigate methods for reducing or controlling the heaving, pitching, and rolling motions and accompanying accelerations during normal cruising operation over waves.
5. Investigate possible means for augmenting GEM lift through improved aerodynamic and air cushion designs.
6. Autopilot stability and control requirements.

MODELS

Dynamically similar models (1/24 scale) of the DTMB Annular Jet and the BuShips Skeg Model (Figures 1 through 7) were used in this investigation. The models were scaled to represent a craft length of 200 feet and to simulate base pressures of 50 to 100 psf. The models were constructed of balsa with mahogany spars for structural integrity.

The BuShips skeg model was constructed in such a manner to permit the installation of three (3) bottom configurations and three (3) skeg configurations. Provisions were also made for utilizing three jet angles (30°, 45°, and 60°). The model was designed with a concave bottom to which alternate flat or convex bottoms could be attached. An additional center line skeg was also included in the model construction. For this investigation, the 45° jet angle with the knife edge skeg was tested in conjunction with the three bottom contours. For the power failure impact tests, a plate inclined at 45° was attached to the bow.

Axial fans powered by one horse power d. c. motors placed on the top of the models supplied the air for the ground effect power. Two fan configurations were used on the DTMB annular model. One fan was utilized for the 50 psf condition and two fans were used for testing in the 70 to 100 psf range. One fan was sufficient to power the BuShips skeg model for the entire range. The internal air flow system, consisting of a common plenum chamber from which air was fed to all of the jets, was similar for both models. The curtain jet widths of both models were made to match the momentum output of the fans. The resulting curtain jet widths for the models were as follows:

DTMB Annular Jet Configuration

Weight Pounds	G Jet Width (ft)
633,834	3.0
906,163 1,121,126	1.25

BuShips Skeg Model

All weights	2.0

TEST APPARATUS AND INSTRUMENTATION

The investigation reported herein was conducted in the towing tank of the General Dynamics/Convair Hydrodynamics Laboratory. The towing tank is 300 feet long, 12 feet wide, and 6 feet deep, with a hydraulically operated overhead towing carriage. A mechanical wave generator capable of producing regular sinusoidal waves is positioned at one end of the tank (Reference 1).

The dynamic-type carriage utilized during these tests consisted of two parallel shafts attached to the model. These shafts were free to move vertically within a support structure. The shafts were also provided with ball bearing pivots to allow the models to pitch at its center of gravity. A photograph of the annular jet model attached to the dynamic carriage is shown in Figure 8.

Data were obtained for the heave, pitch, acceleration, wave size and velocity. The time histories for all of the components used during the test were recorded on a Midwestern Model 616 direct writing oscillograph placed on the carriage. Heave and pitch measurements were obtained by the use of high resolution potentiometers. Accelerations were measured with two accelerometers placed fore and aft on the central mahogany spars 30 inches from the center of gravity. Force measurements were obtained using strain gage dynamometers incorporated in a balanced Wheatstone bridge circuit.

The wave size was determined by a sonic wave recorder developed by the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. The wave recorder was placed adjacent to the bow of the models in order to record the undisturbed wave contours. Data for wave height, wave length, and frequency of encounter were obtained from the time correlation record.

Model velocity was recorded by two methods. A continuous trace of the velocity profile was obtained using a d.c. generator placed on the carriage. A secondary method utilized a photo-electric cell placed on the carriage which was de-energized by strips placed every five feet on the rail support. Both methods were used simultaneously during this program.

Motion pictures of the motions of the model were obtained using a Bell and Howell camera mounted on the moving carriage. The motion pictures were taken at a standard film speed of 24 frames per second in order to present the motion in "real" model time. It should be pointed out, however, that full scale prototype motions would occur at approximately one-fifth the rate of the model, i.e., model time varies as the $(\text{scale})^{1/2}$.

TEST PROCEDURE AND CONDITIONS

The model tests were conducted in two phases. Phase one consisted of the determination of the analog computer input data for Reference 2. The second phase incorporated the dynamic tests for the comparative evaluation of the two GEM configurations.

PHASE I (ANALOG COMPUTER INPUT DATA)

This phase utilized the DTMB annular model and the following tests were performed:

1. The determination of the heave response in one degree of freedom. The model was locked in pitch at zero degrees trim and data were obtained at constant velocities up to 100 knots, full scale, for wave lengths of .5 to 2 times the length of the craft. Test wave heights were of the order of 1.0 to 1.5 times the hover height over the ground board.
2. Tests for determining the pitch response of the model in one degree of freedom. The model was locked in heave at the over-water hover height and data were obtained in the same manner as in (1). Tests were made in a wave height of 1.0 times the hover height over the ground board.
3. Vertical drop tests for the evaluation of impact velocity and accelerations. The drops were made in smooth water at three power settings and one power-off condition.
4. The evaluation of aerodynamic lift coefficient at zero angle of attack. Data were obtained with a strain

gage dynamometer with the model operating at constant velocities over smooth water.

PHASE II (COMPARISON OF LOADS OF MOTION OF THE TWO GEM CONFIGURATIONS)

The two GEM configurations were tested in the following conditions:

1. Hovering and operating at speeds up to 100 knots, full scale, in smooth water and in waves. Data were obtained at constant velocities with the model in two degrees of freedom, i.e., in heave and in pitch. The model was tested in wave lengths of .5 to 2 times the length of the craft and in wave heights of .5 to 1.0 times the hover height over ground board. Tests in following seas, as well as head seas, were made for each configuration.
2. Total power failure at cruising speed while operating in waves. Sudden power failure conditions were simulated and impact accelerations were obtained in wave lengths of .5 x 2.0 times the length of the craft and wave heights of 5 to 1.0 times the hover height over the ground board.

The power failure test procedure was as follows:

1. The model was accelerated to constant speed in waves.
2. The motor was automatically cut off 160 feet from the start by a microswitch actuated by a lever on the rail support. The microswitch actuated a relay in the fan circuit. The carriage was also uncoupled from the drive system and was permitted to decelerate at this time.

3. After the model impacted the first wave, the fan was turned on by a remotely controlled manual switch by-passing the micro-switch. This procedure was used to prevent the possible destruction of the model. The DTMB model was totally destroyed after six test runs.

In addition to the above tests, the floating characteristics of the BuShips skeg configuration were recorded in waves.

Table I lists the configurations and the conditions that were investigated during the dynamic tests.

TABLE I

TEST CONDITIONS

Model	Configuration	Weight Pounds	Full Scale Base Pressure PSF	Moment of Inertia Slug-ft^2
DTMB Annular Jet		633,834	50.302	2.41×10^7
		906,163	78.087	3.36×10^7
		1,121,126	100.022	3.55×10^7
BuShips side skeg with knife-edged skeg	Flat bottom	812,160	59.443	6.64×10^7
		1,026,432	77.414	8.72×10^7
	Concave bottom	866,765	65.042	7.00×10^7
	Convex bottom	1,041,224	78.796	8.19×10^7

The methods used to determine the base pressure and the moment of inertia of the models were as follows:

Base Pressure:

The operating base pressure for the DTMB annular configuration was determined from the equation

$$W = L = (\Delta p + .42q)S \qquad \text{(As given by Ref. 3)}$$

For the BuShips skeg configuration, the following equation was used:

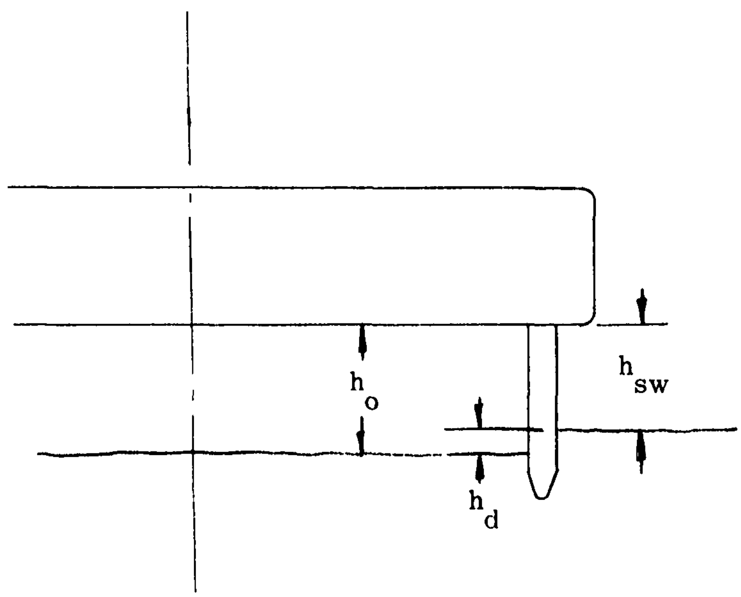
$$W = L = \Delta pS + J \cos \Theta + L_B$$

Since from the simple thin jet theory

$$J = \frac{\Delta p\, h_o\, C}{1 - \sin \Theta},$$

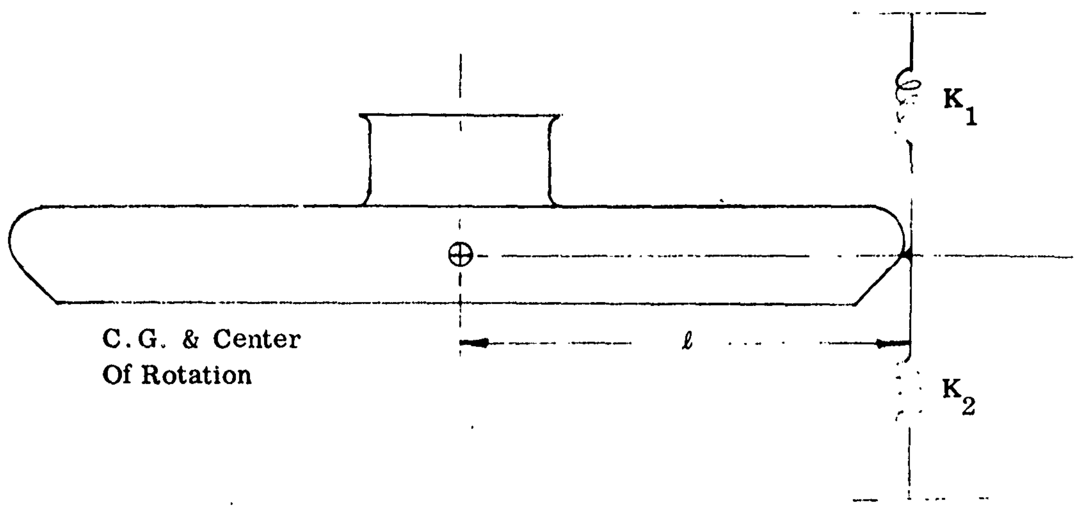
$$W = L = \Delta pS + \frac{\Delta p\, h_o\, C}{(1 - \sin \Theta)} (\cos \Theta) + L_B$$

where h_o was assumed to be equal to $h_{sw} + h_d$ and h_d = base pressure in inches of water.



Moment of Inertia

The moment of inertia of both models was determined by the method identical to that used by General Dynamics/Convair for seaplane models.



$K_{equir} = K_1 + K_2 = 3.78$ #/in

Since $\quad \Delta M = K_e \ell^2 \Delta \Theta$

$$\frac{\Delta M}{\Delta \Theta} = K_e \ell^2 = K_p$$

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{K_p}{I}}$$

$$I = \frac{K\ell^2}{f^2 (2\pi)^2}$$

DISCUSSION

MODEL NATURAL FREQUENCIES

It is well established that a critical speed exists for the ground effect machine operating over uneven surfaces. The critical speed depends upon the operating height, the ratio of vehicle length to wave length, the amplitude of the wave, and the damping factor.

Reference 4 indicates that the heave spring constant, K_h, for a GEM is approximately

$$K_h = \frac{\Delta L}{\Delta h} = \frac{W}{h_o}$$

and the natural undamped frequency in heave for a GEM is approximately

$$fn = \frac{1}{2\pi}\sqrt{\frac{g}{h_o}}$$

The expression for the pitch natural frequency can be developed by the same analogy. It it is assumed that

$$K_h = \frac{\Delta L}{\Delta h} = \frac{W}{h_o}$$

is the same for each compartment of the GEM base area, then

$$\Delta L_c = W \frac{\Delta h_c}{h_o}\left(\frac{S_c}{S}\right)$$

Also, by assuming that the lift acts at the centroid of each compartment, the moment equation can be written as

$$\Delta M = W \frac{\Delta h_{c_1}}{h_o}\left(\frac{S_{c_1}}{S}\right) r_{c_1} \text{ - - - - - - - - } W \frac{\Delta h_{c_n}}{h_o}\left(\frac{S_{c_n}}{S}\right) r_{c_n}$$

Since the compartmentation of the configurations used in this investigation was symmetrical, the expression reduces to

$$\Delta M = \frac{2\ W\ (S_{c_1}/S)\ r_{c_1}{}^2\ \Delta\Theta}{h_o}$$

and the pitch spring constant, K_p,

$$K_p = \frac{\Delta M}{\Delta \Theta} = \frac{2\,W\,(S_{c_1}/S)\,r_{c_1}^{\,2}}{h_o}$$

The undamped pitch natural frequency for the configurations tested is

$$fn_p = \frac{1}{2\pi}\sqrt{\frac{K_p}{I}} = \frac{1}{2\pi}\sqrt{\frac{2\,W\,S_{c_1}\,r_{c_1}^{\,2}}{I\,S\,h_o}}$$

HEAVE AND PITCH RESPONSE

The results of the heave and pitch response tests are presented as the ratios (amplitude of response) divided by (amplitude of disturbance) versus the ratio of (frequency of disturbance) divided by (natural frequency), i.e., ($\Delta h/h_w$ vs fe/fn)

Figures 10 and 11 show the heave and pitch response data obtained with the DTMB configuration for the analog computer study (i.e., single degree of freedom). It is noted that the maximum response is obtained at fe/fn of less than 1.0, which is typical of damped second order systems. The maximum heave response varies with the ratio λ/L and shows an increase with increasing λ/L.

The heave and pitch response characteristics of the DTMB annular jet in two degrees of freedom are plotted in Figures 12 and 13, respectively. Figures 14 and 15 are the heave and pitch responses for the BuShips skeg configuration.

The cross plots of the dynamic test data to determine the effect of base pressure on the dynamic response and on the critical frequency ratio are shown in Figures 16 and 17. Due to the difficulty in obtaining exactly the same wave characteristic for every test condition, a comparison is given for only one wave size. The maximum heave response decreases with an increase in base pressure for the annular jet model while the inverse is true for the BuShips skeg configuration. The maximum pitch response increases with base pressure for both configurations (Figure 16).

The critical frequency ratio in heave decreases for both configurations as base pressure increases For the annular jet configuration, the critical frequency ratio in heave appears to be in the region of .80 to .60 for base pressures of 50 to 100 psf, respectively. The BuShips skeg configuration shows a critical heave frequency of 1.0 to .75 for the same base pressure range. The critical frequency ratio in pitch for both configurations was constant at .55 for the DTMB annular configuration and at .40 for the BuShips skeg configuration (Figure 17). It is to be noted, however, that the two configurations were not tested at the same G/h_o. The critical frequency is dependent on the damping ratio ζ, by the expression

$$\frac{f_p}{f_n} = \sqrt{1 - 2\zeta^2}$$

and ζ is a function of the operating height, h_o.

Data for the BuShips side skeg configuration with the convex bottom were not obtained for reasons explained later in this report

At a frequency ratio higher than the critical, it was observed that the model tended to maintain itself in a level flight. However, even at the λ/L of .50 and cruising velocity equivalent to 100 knots, the model did not settle to a smooth and level flight but vibrated at the frequency equal to the frequency of wave encounter.

LOADS

The accelerations of both configurations tested in this investigation were measured by the use of two accelerometers placed 30 inches fore and aft of the center of gravity and rotation. Data are presented for the maximum acceleration above +1g static, encountered during operation over waves.

Operational Loads

The forward accelerations measured for both the DTMB and the BuShips configurations were of the order of 1.0 g (Figures 18 and 19), and appear to occur at the peak heave frequency ratio.

The c.g. accelerations were computed by the expression,

$$acc_{c.g.} = \frac{\text{forward acceleration} + \text{aft acceleration}}{2}$$

at the instant of maximum c.g. accelerations as determined from the heave traces (the model was assumed to be a rigid body). The data are shown in Figure 20. The maximum c.g. acceleration measured was .60 of a g for the DTMB configuration and .50 of a g for the BuShips configuration, and it seems to occur at the peak heave frequency ratio. Cross plotting the maximum c.g. acceleration versus wave height shows that the accelerations increase with the wave height for both configurations. The BuShips concave bottom exhibited a more pronounced increase in c.g. acceleration than did the flat bottom configuration (Figure 21). For the DTMB annular GEM, Figure 21 shows that for a given wave length the maximum c.g. accelerations generally decrease with the gross weight. Gross weight increase for the BuShips side skeg GEM shows an increase in c.g. accelerations.

Data for the maximum aft accelerations are presented in Figures 22 and 23. The maximum aft accelerations for both configurations are of the order of .60 of a g.

Impact Loads

Impact accelerations incurred by both configurations during sudden power failures are presented for a forward velocity of 87.5 knots in Figure 24. The maximum g's obtained at the fore and aft accelerometers are plotted versus λ/L. Table II lists the actual readings obtained.

The procedure used during the impact tests in waves was previously mentioned. The procedure permitted at least two runs for each of the wave conditions tested. The following visual and time history trace observations were made during this test:

1. Accelerations were obtained for the first wave impact only.
2. The impact occurred chiefly at the nose of the model.
3. No impact occurred at the midsection of the model, except at $\lambda/L = .50$.
4. Both models suffered extensive damage in λ/L of .50 when the transverse jets acted as scoops.

SMOOTH WATER TESTS

Preliminary tests of power failures were made in smooth water with the BuShips configuration to check out the test procedure. Time history data were also taken at this time and the following conditions were observed:

1. At a forward velocity of 10 feet per second, the model impacted the water approximately 2 seconds after the fan was cut off when the initial operating height was 2.5 inches.
2. The vertical impact acceleration at all points of the model was essentially zero.

It was concluded from the above that the fan dynamics and the ground effect cushion have a pronounced effect on the glide of a GEM.

The results of the smooth water tests are presented in Figures 25 through 27. Figure 25 shows the average operating height in waves plotted along with the operating height over smooth water. This substantiates the findings of Reference 7 that the mean flight path over the wave is essentially the same as that over smooth water measured from the mean water level. It can be seen also from the hovering condition that the BuShips configuration operated at a much higher height than did the DTMB configuration with the same base pressure and power input. During this test, the BuShips model hovered at a height approximately 2.5 times the hover height of the DTMB model.

A maximum trim of 3° was encountered by the DTMB annular jet configuration at approximately 30 knots. The hump trim for the BuShips side skeg configuration with the flat bottom is only of the order of .5° at 40 knots. The BuShips skeg configuration with the concave bottom exhibited a hump trim exactly like that of the flat bottom, except that a divergent trim condition was observed, starting at a velocity of 60 knots to a maximum trim of 1.5° at 87.5 knots (Figure 26).

Attempts to test the BuShips side skeg configuration with the convex bottom installed were made in smooth water without success. At the forward speed of 30 knots, the model pitched excessively because the water attached itself to the curved bottom. This was probably due to the low pressure suction on the convex bottom.

Jet extensions were utilized to determine the extent of convexity that might be tolerated on the bottom, and not until the jet extension was approximately even with the convex bottom did the model operate with any success. It is therefore concluded that the convex bottom was an intolerable configuration for a side skeg GEM.

Drag measurements for the two GEM configurations are plotted versus velocity in Figure 27. The DTMB configuration exhibits a much lower D/w ratio than the BuShips skeg configuration At the operating velocity of 100 knots, the DTMB configuration had a D/w ratio of 0.1, whereas the BuShips configuration had a D/w ratio of 0.5.

<u>Afloat</u>

Model test of the BuShips side skeg model were performed to determine the floating characteristics. The data are presented for the heave amplitude ratio ($\Delta h/h_w$) vs λ/L in Figure 28 and trim to λ/L in Figure 29.

The flat bottom configuration heaves more severely (approximately twice as high) than the concave bottom configuration for the same wave condition. The flat bottom configuration shows a heave amplitude ratio of .80 compared to the concave bottom configuration heave amplitude ratio of .40 (Figure 28).

The trim characteristics of the two types of bottom were found to be of the same magnitude for the two wave conditions tested (Figure 29).

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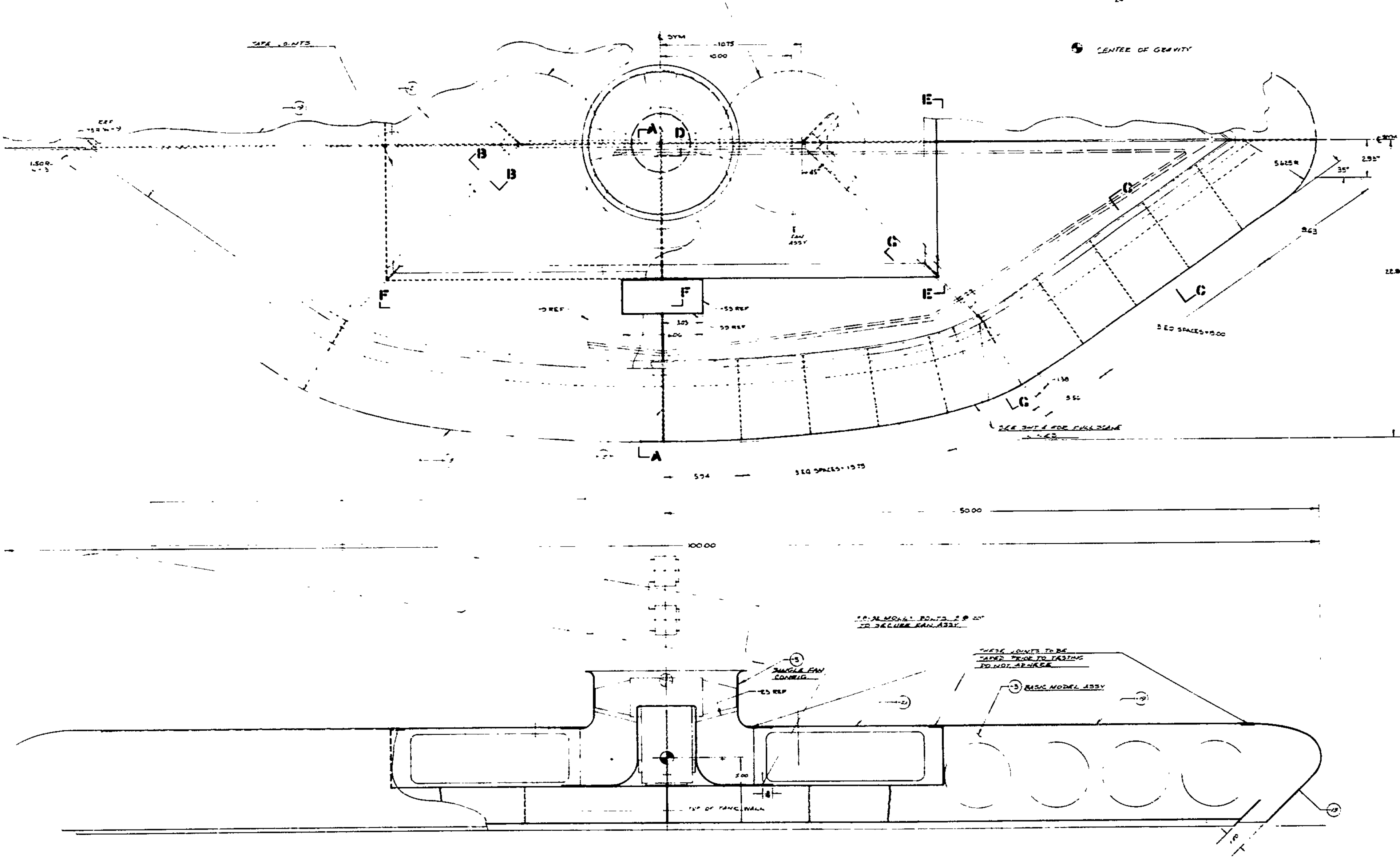
FIG
ANNULAR JET
MODEL
1/24 SCALE



Loads and Motion Study of Two Types of GEM Vehicles

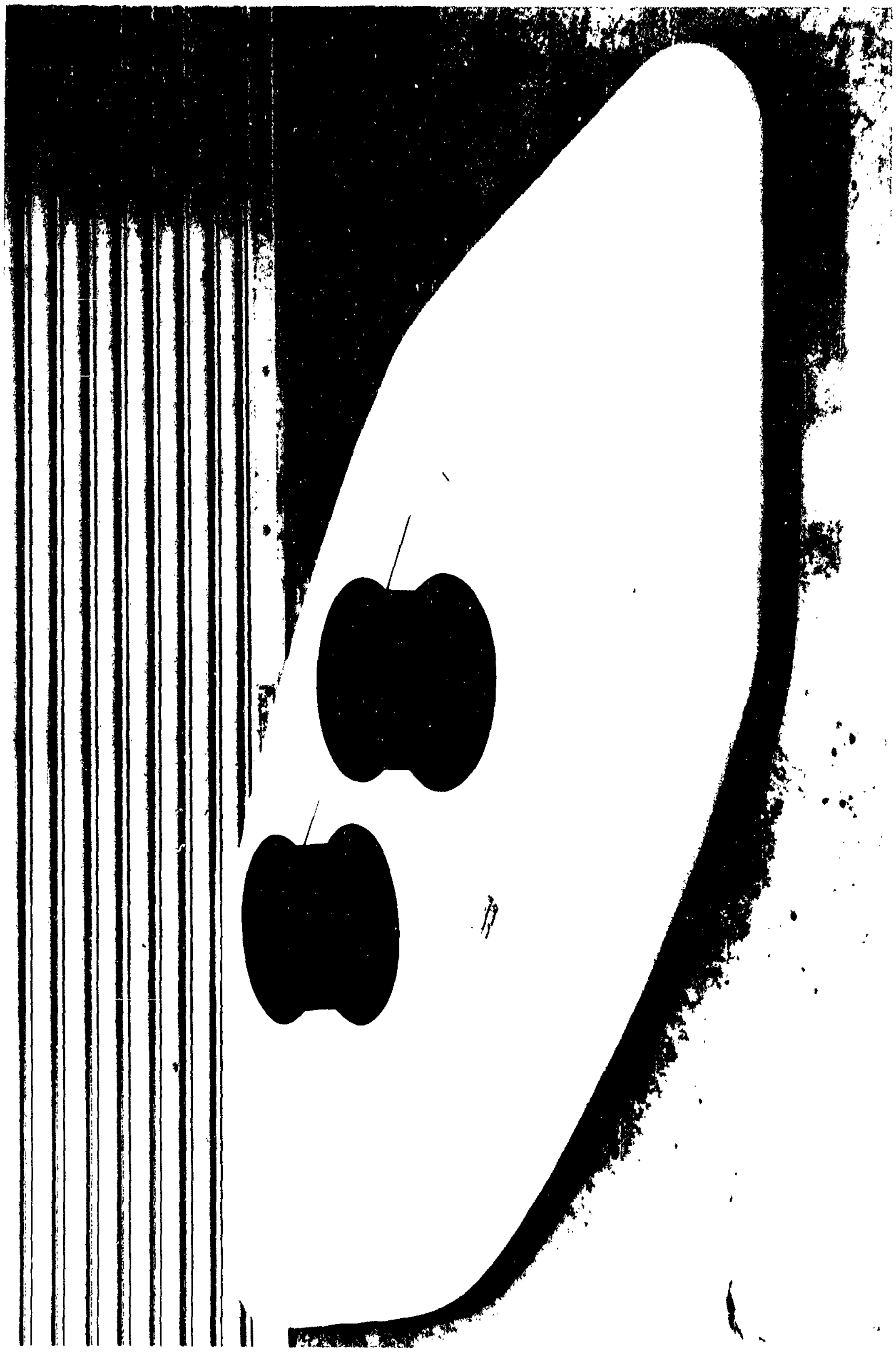


Figure 2 Top Plan View (DTMB Annular Jet Configuration)

Loads and Motion Study of Two Types of GEM Vehicles

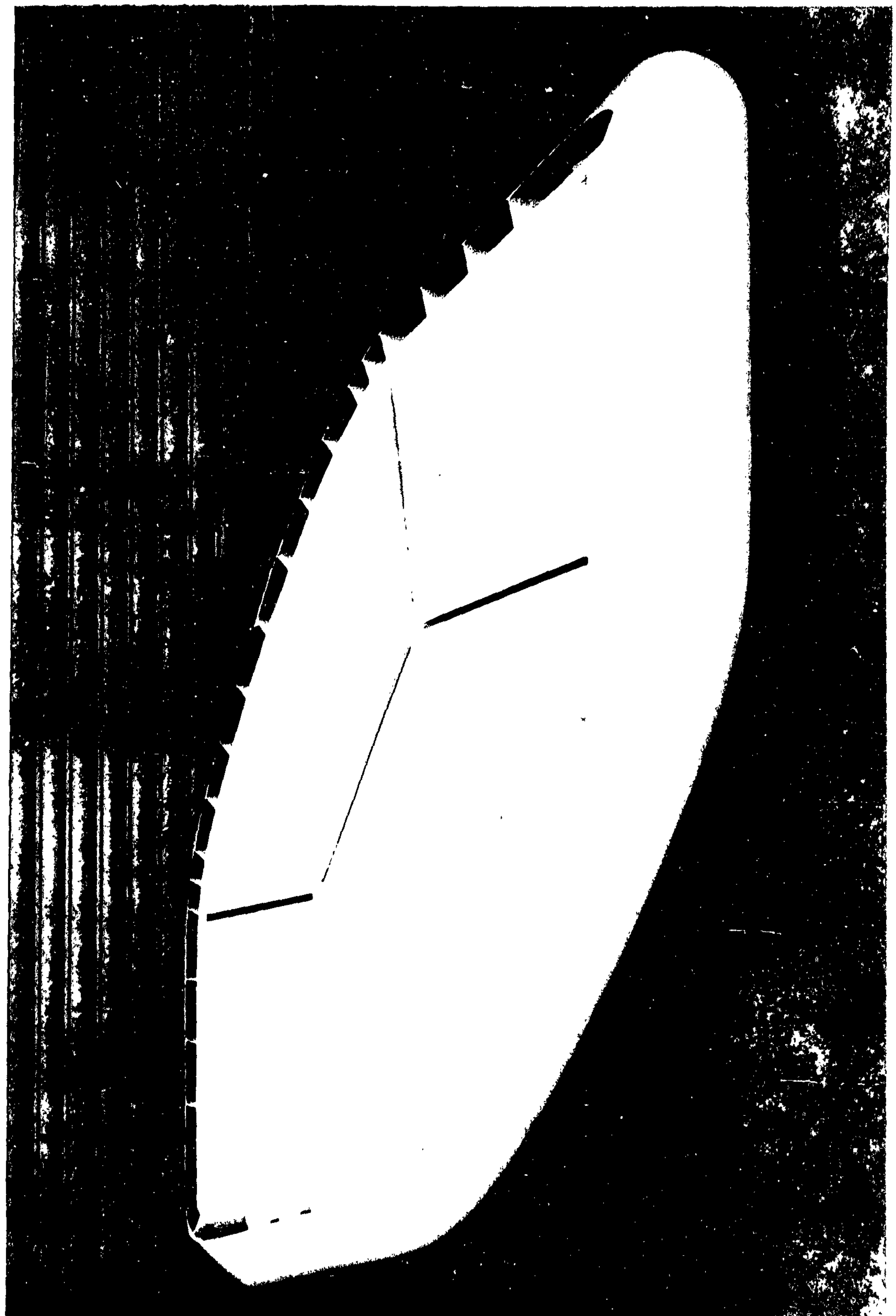
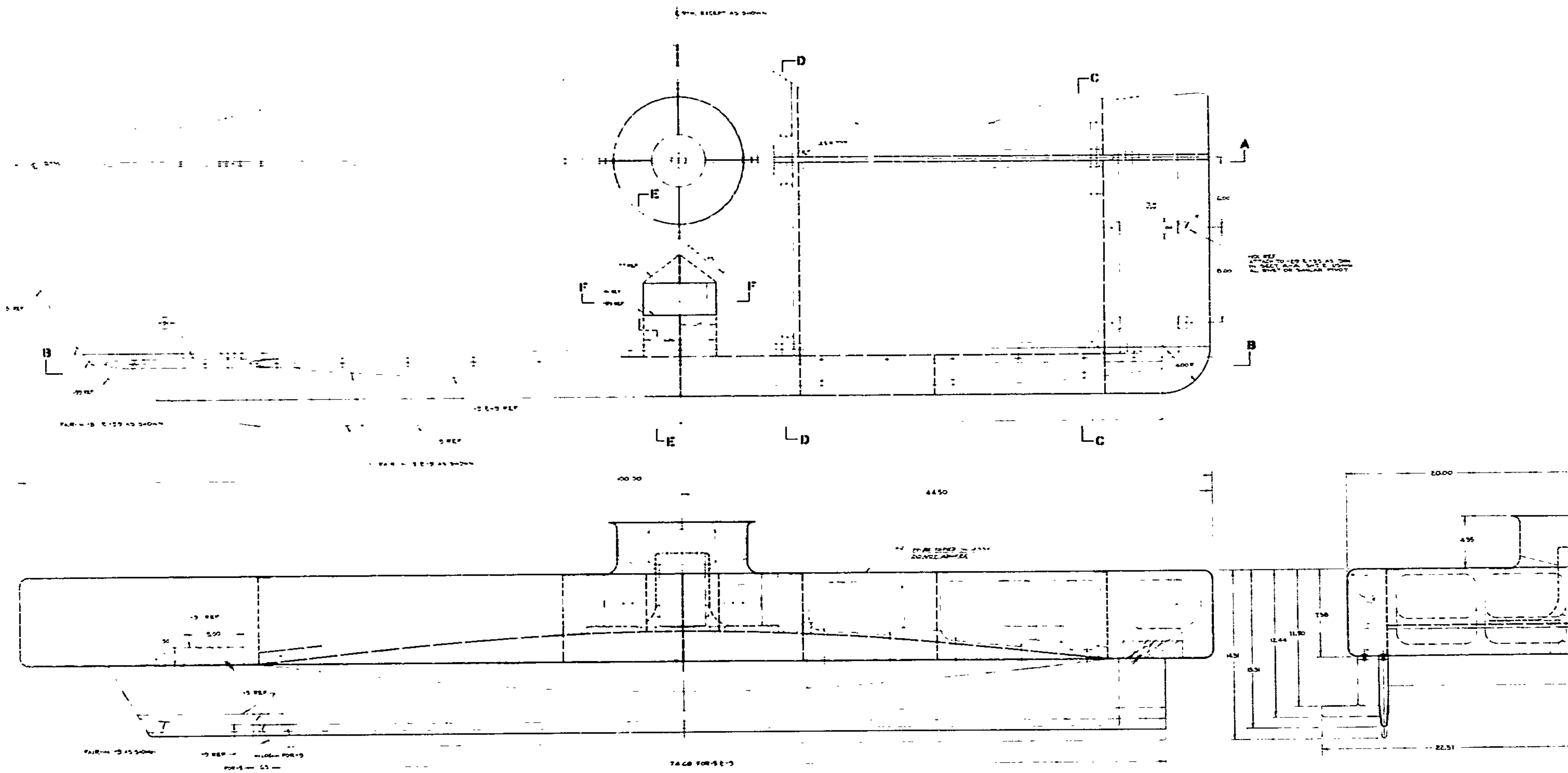


Figure 3 Bottom Plan View (DTMB Annular Jet Configuration)

FIG 4
CEM WING MODEL

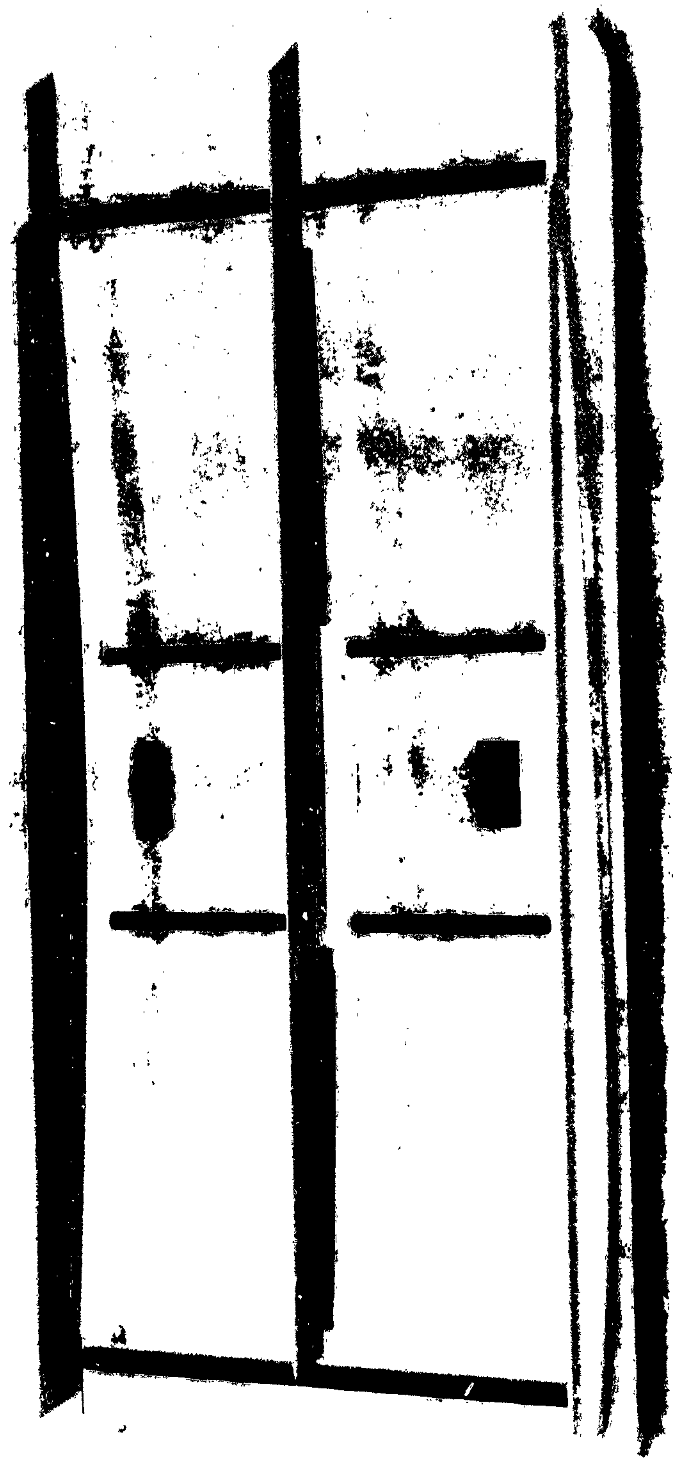


Loads & Motions Study of Two Types of GEM Vehicles

Top Plan View (BuShips "Skeg" Configuration)

#69373

Loads & Motions Study of Two Types of GEM Vehicles



#69372

Bottom Plan View (BuShips "Skeg" Configuration)

Loads & Motions Study of Two Types of GEM Vehicles

#69374

Alternate Bottom and Skeg Configurations (BuShips "Skeg" Configuration)

Loads and Motions Study of Two Types of GEM Vehicles

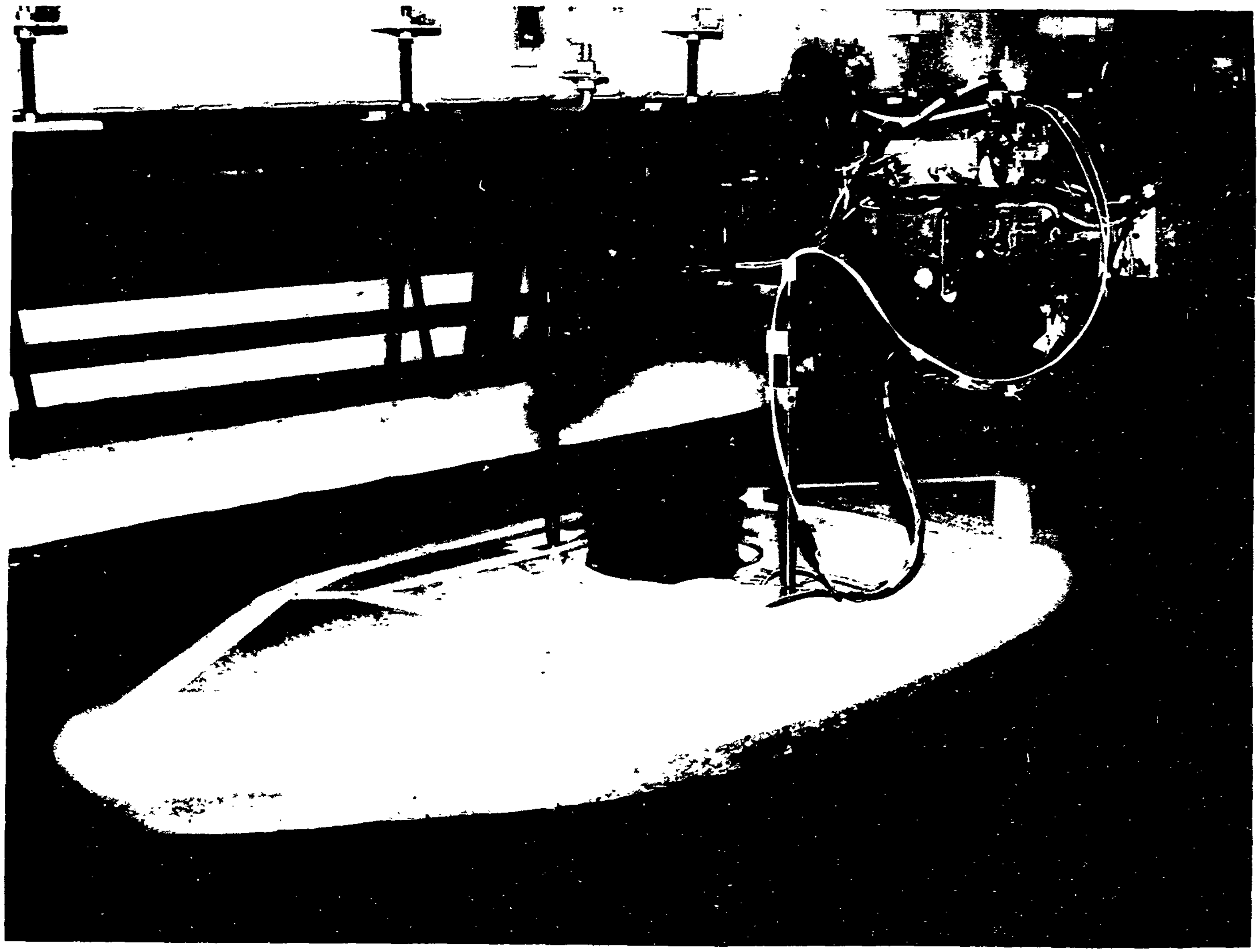


Figure 8 Static Operation over Water (DTMB Configuration)

DTMB Annular GEM Model
Model Weight = 633, 834 Lbs.
Static Height over Ground Board (h_o)

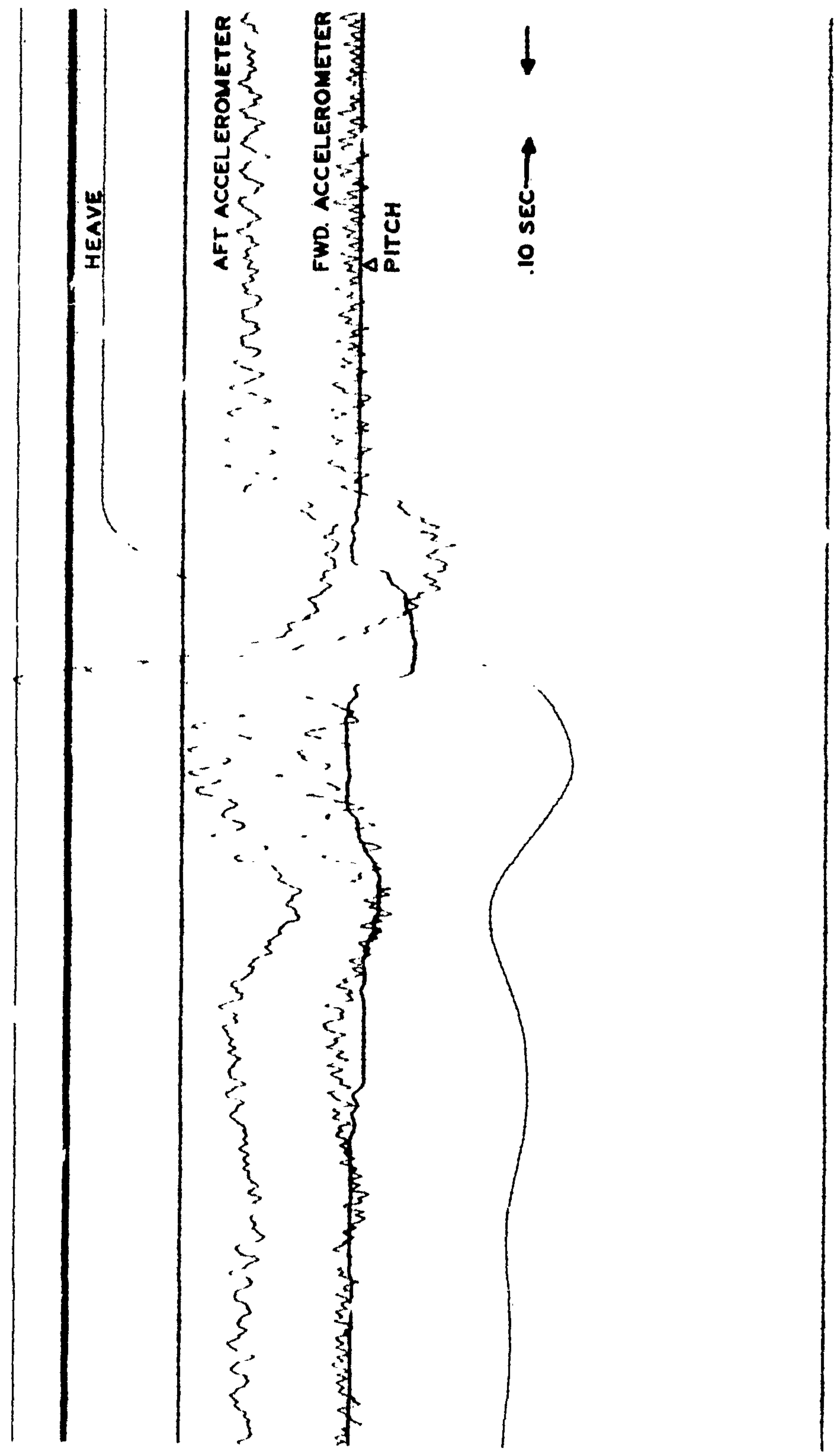


Figure 9 Typical Oscillograph Trace for Vertical Drop Test

Note: Model fixed in trim at 0 deg.
Model weight = 39.7 lb.
(G.W. = 548,813 lb.)
G/h_o = 1.5

Symbol	λ/L	h_w/h_o
⊙	1.993	.987
⊡	1.573	.957
▽	1.168	1.206
△	.520	1.059

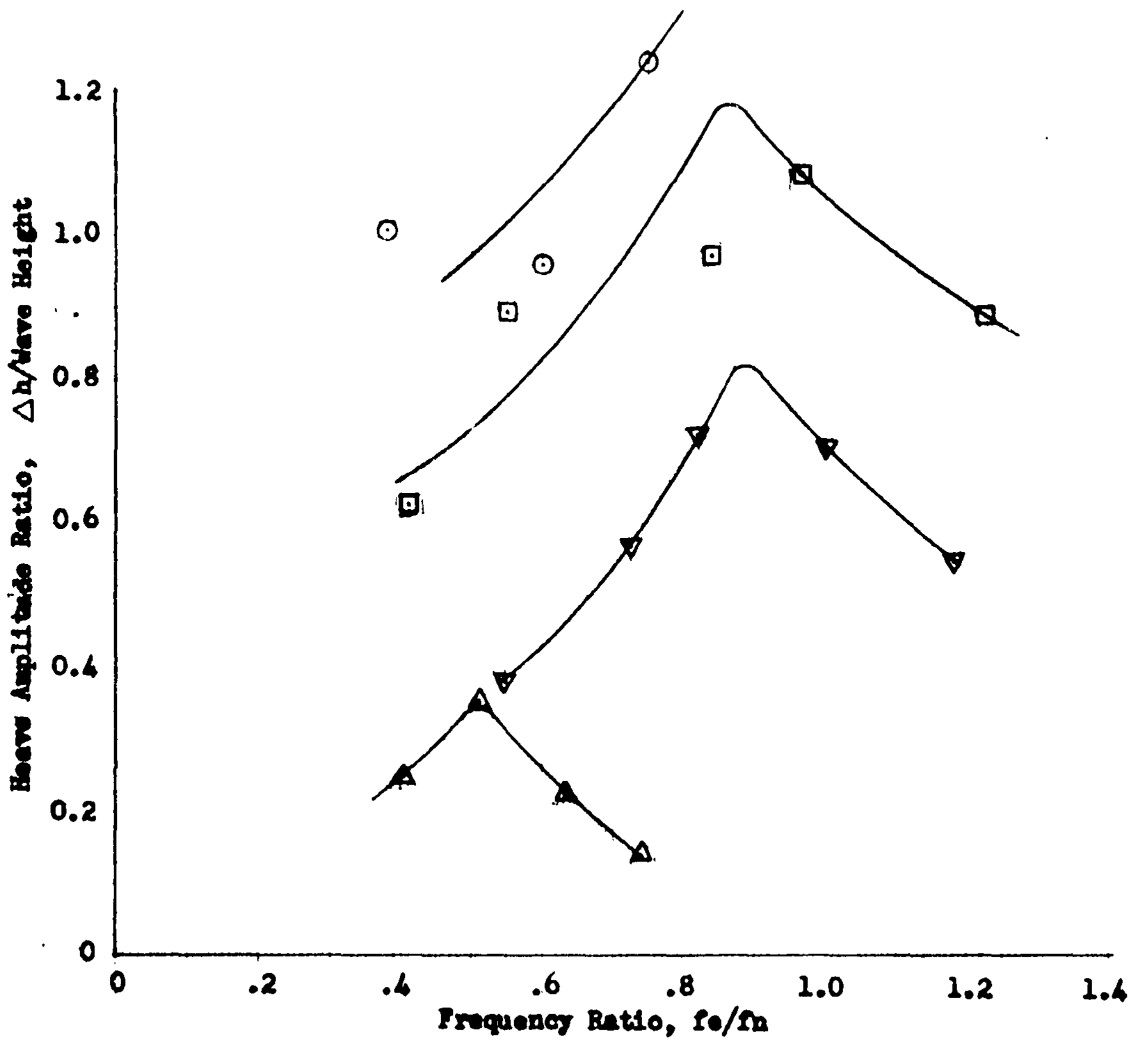


FIG. 10. HEAVE RESPONSE FOR DTMB ANNULAR GEM

Symbol	λ/L
⊙	1.993
⊡	1.513

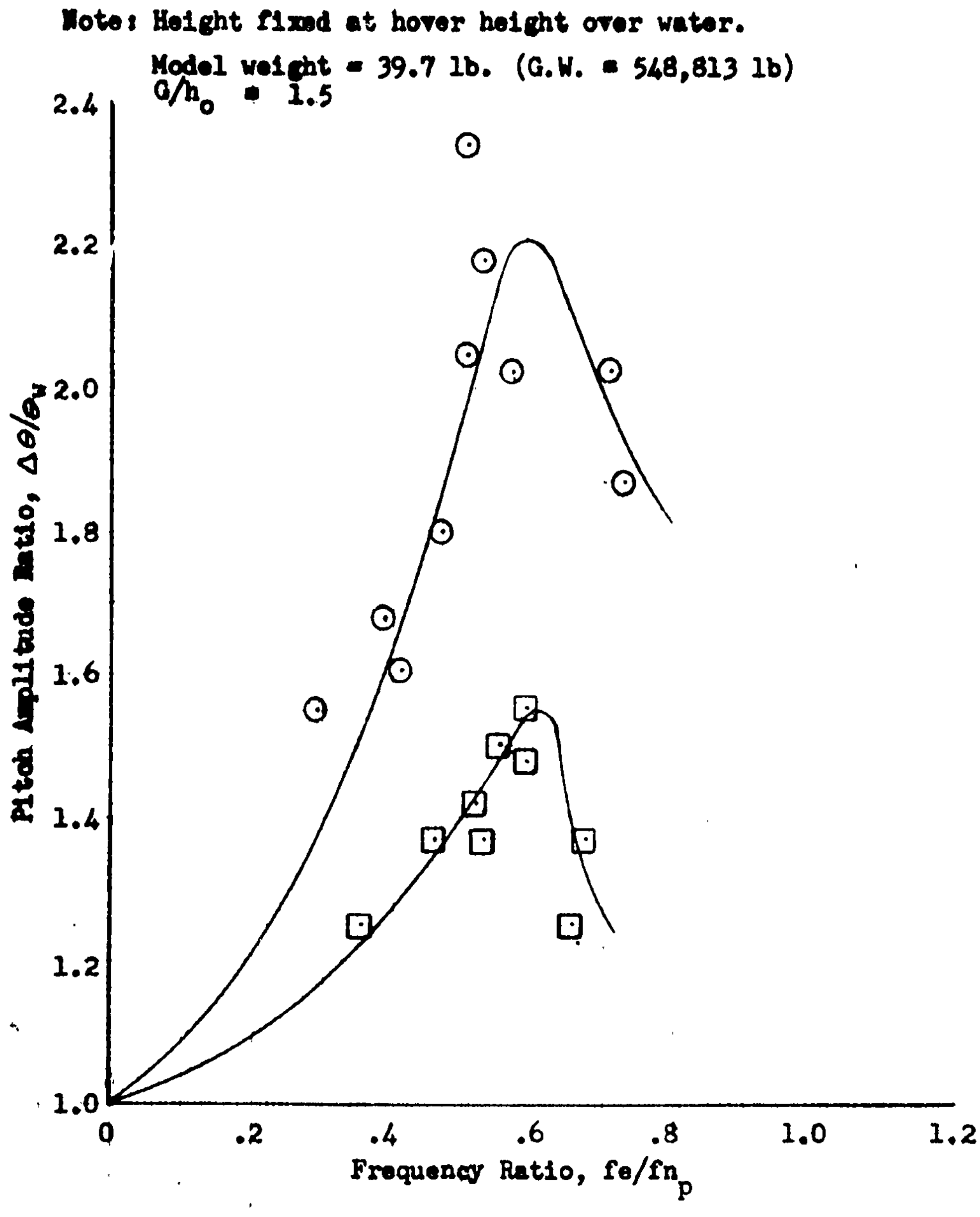


FIG. 11. PITCH RESPONSE FOR DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	2.00	.984
⊡	1.31	.962
△	.56	.944
▽	1.77	1.55
×	1.33	1.25
◊	1.21	1.16

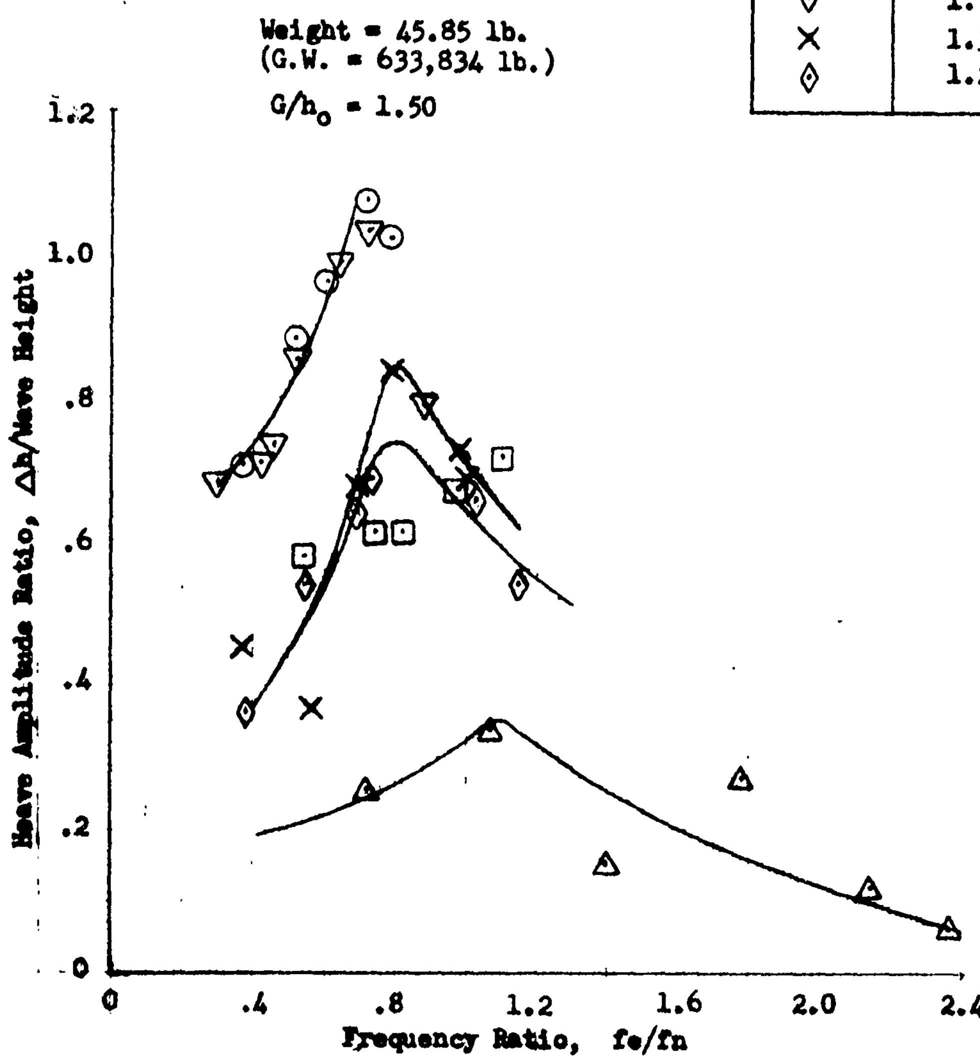


FIG. 12. HEAVE RESPONSE DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	1.614	1.612
⊡	1.440	1.166
△	1.362	1.720

G/h_o = .960
Weight = 65.55 lb. (G.W. = 906,163 lb)

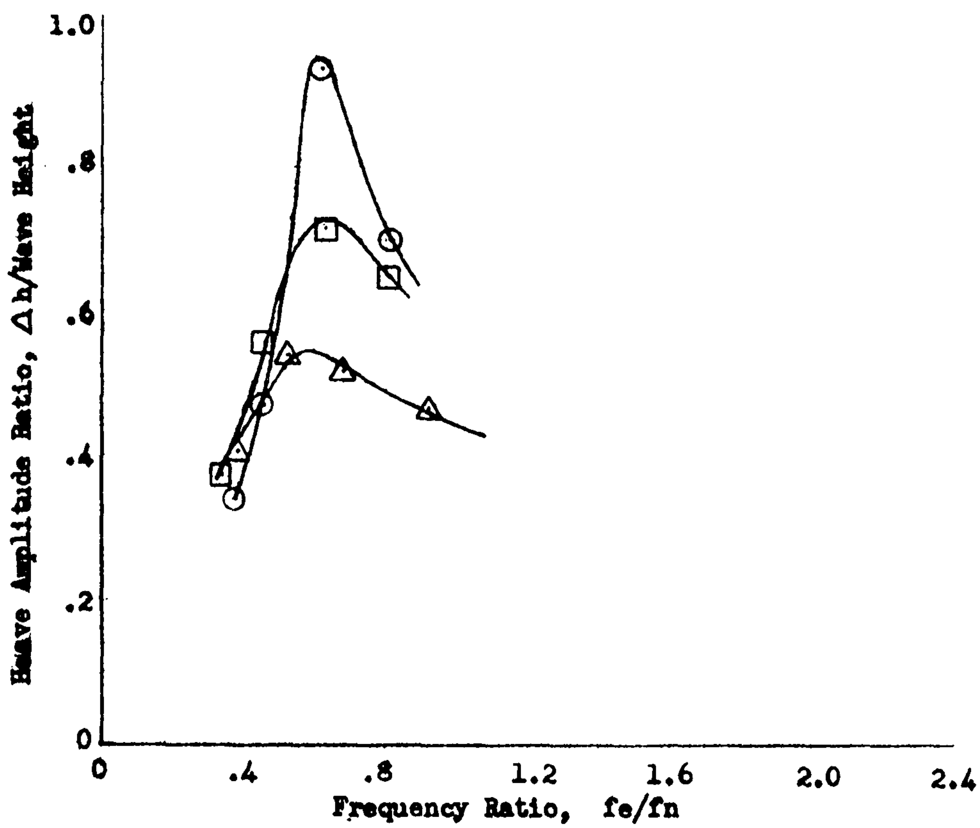


FIG. 12. HEAVE RESPONSE DTMB ANNULAR GEM
(CONTINUED)

Symbol	λ/L	h_w/h_o
⊡	1.438	1.294
△	.554	1.247

G/h_o = .737
Weight = 81.10 lb. (G.W. = 1,121,126 lb)

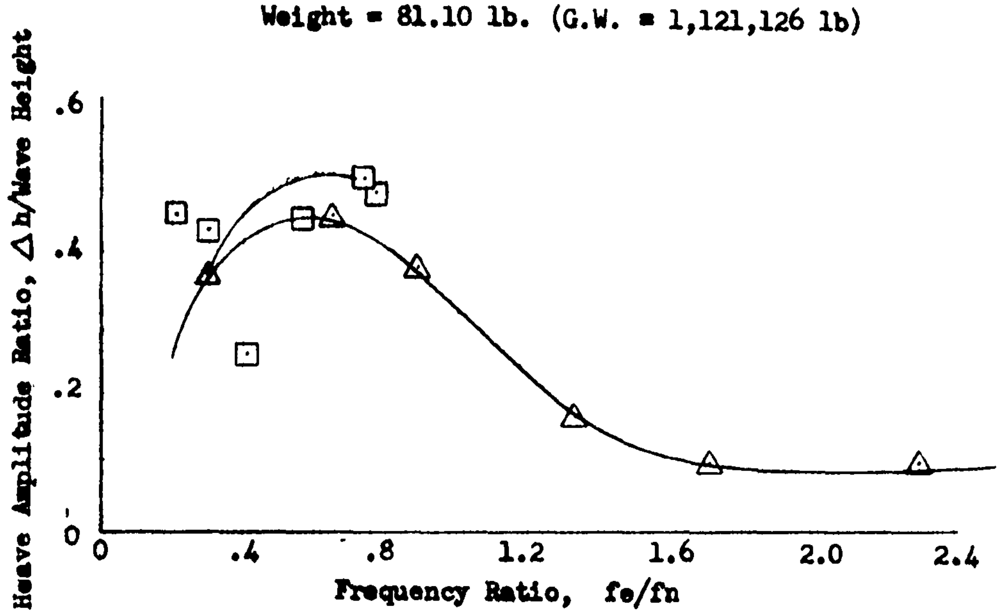


FIG. 12 HEAVE RESPONSE DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊙	2.00	.984
⊡	1.314	.962
△	.558	.944
▽	1.771	1.550
×	1.328	1.250
◊	1.215	1.160

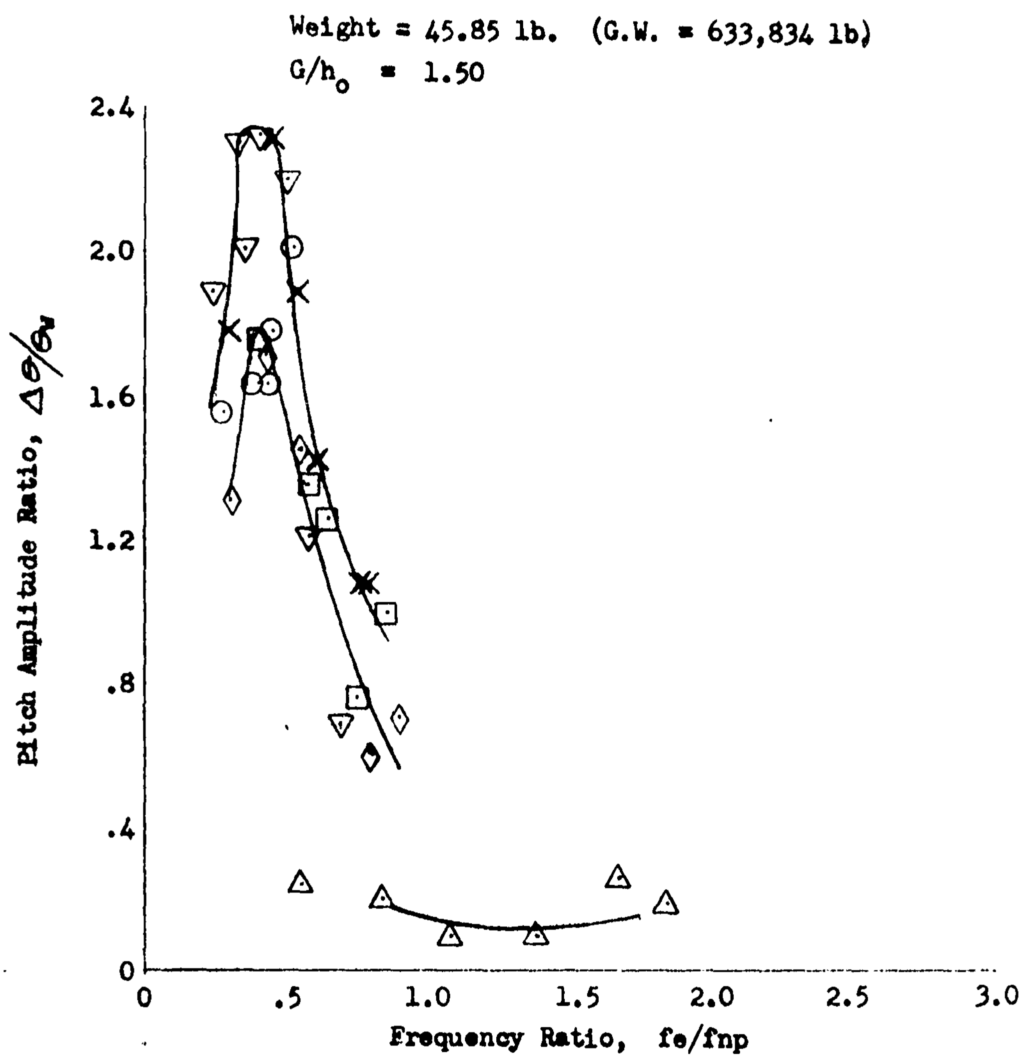


FIG. 13. PITCH RESPONSE FOR DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	1.614	1.612
⊡	1.440	1.166
△	1.362	1.720

G/h_o = .960
Weight = 65.55 lb. (G.W. = 906,163 lb)

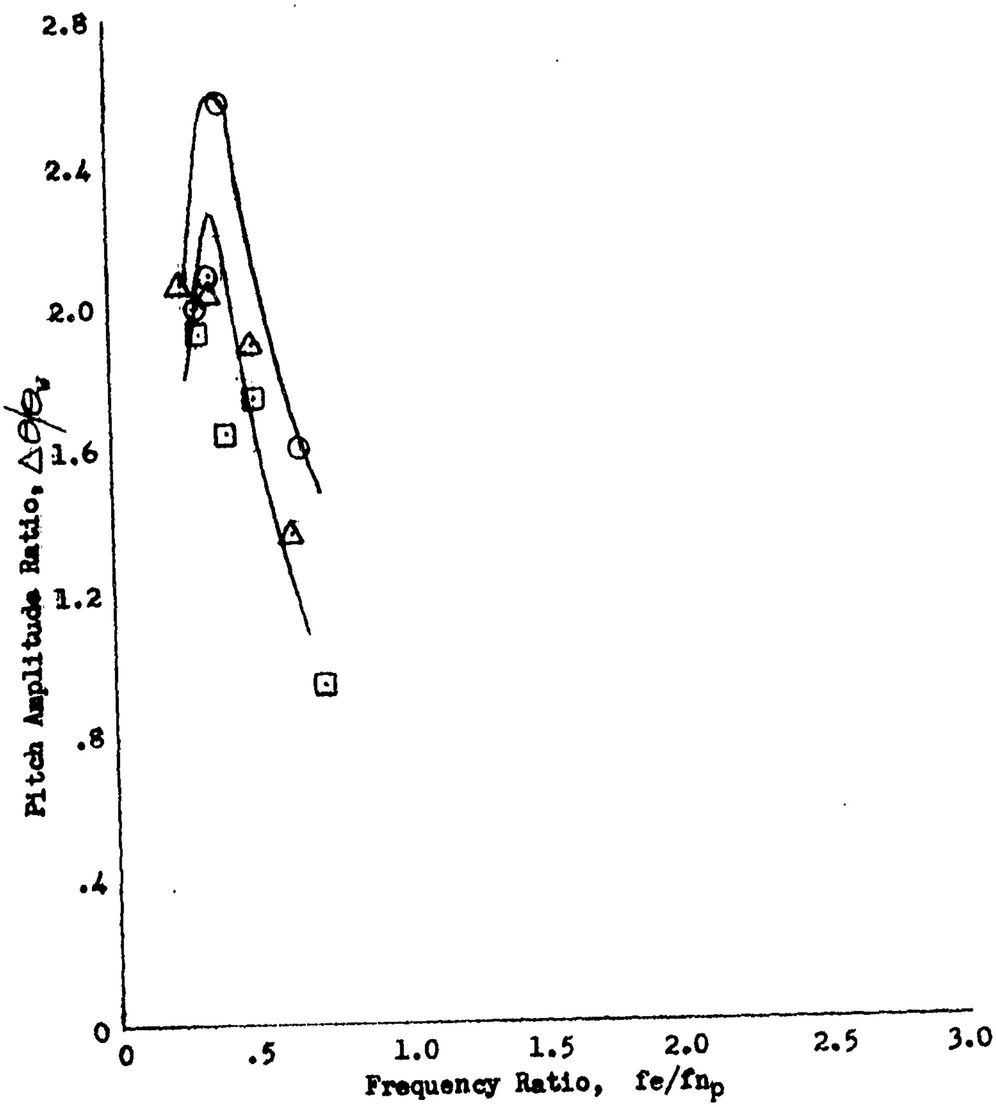


FIG. 13. PITCH RESPONSE FOR DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊡	1.438	1.294
△	.554	1.247

G/h_o = .737

Weight = 81.10 lb. (G.W. = 1,121,126 lb)

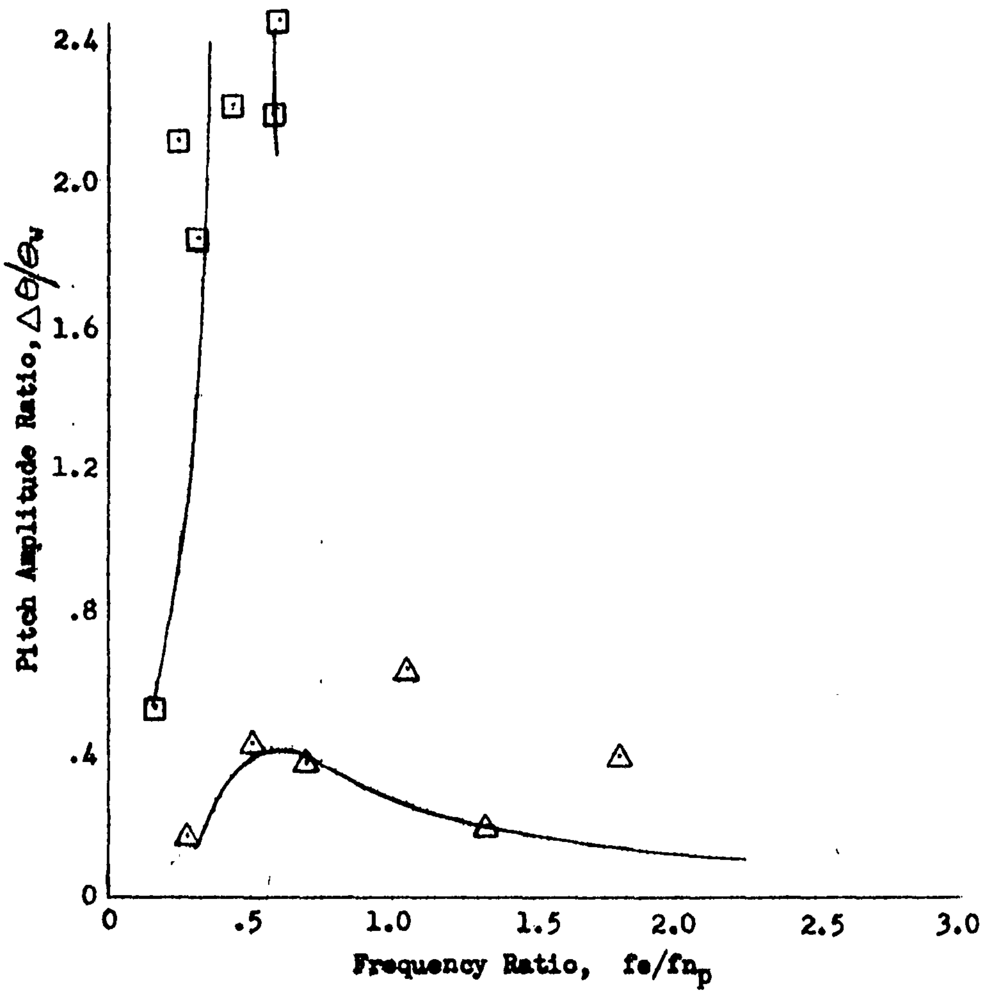


FIG. 13. PITCH RESPONSE FOR DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.599	.349
⊡	1.353	.368
△	.560	.358
▽	1.656	.854
×	1.262	.765
◊	.634	.760

Flat Bottom Skeg Model
G/h_o = .333
Weight = 58.75 lb. (G.W. = 812,160 lb)

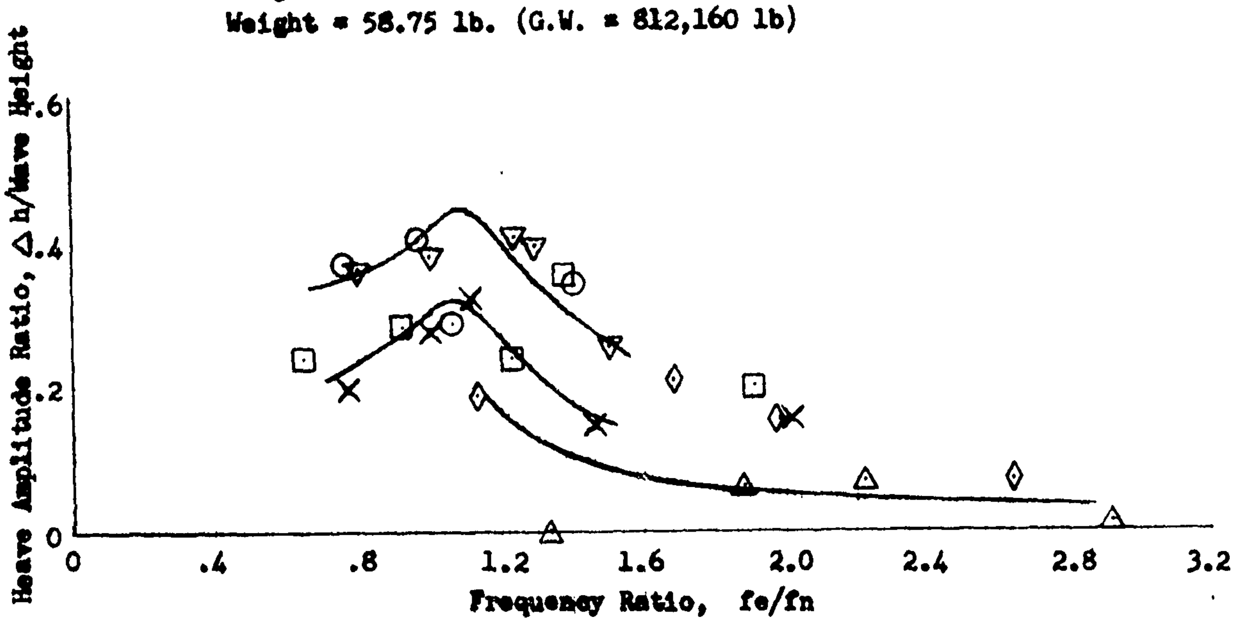


FIG. 14. HEAVE RESPONSE FOR BUSHIPS SKEG MODEL

Symbol	$\lambda/_L$	h_w/h_o
⊙	1.64	.402
⊡	1.319	.460
△	.565	.4375
▽	1.782	1.039
×	1.289	.924
◊	.704	.698

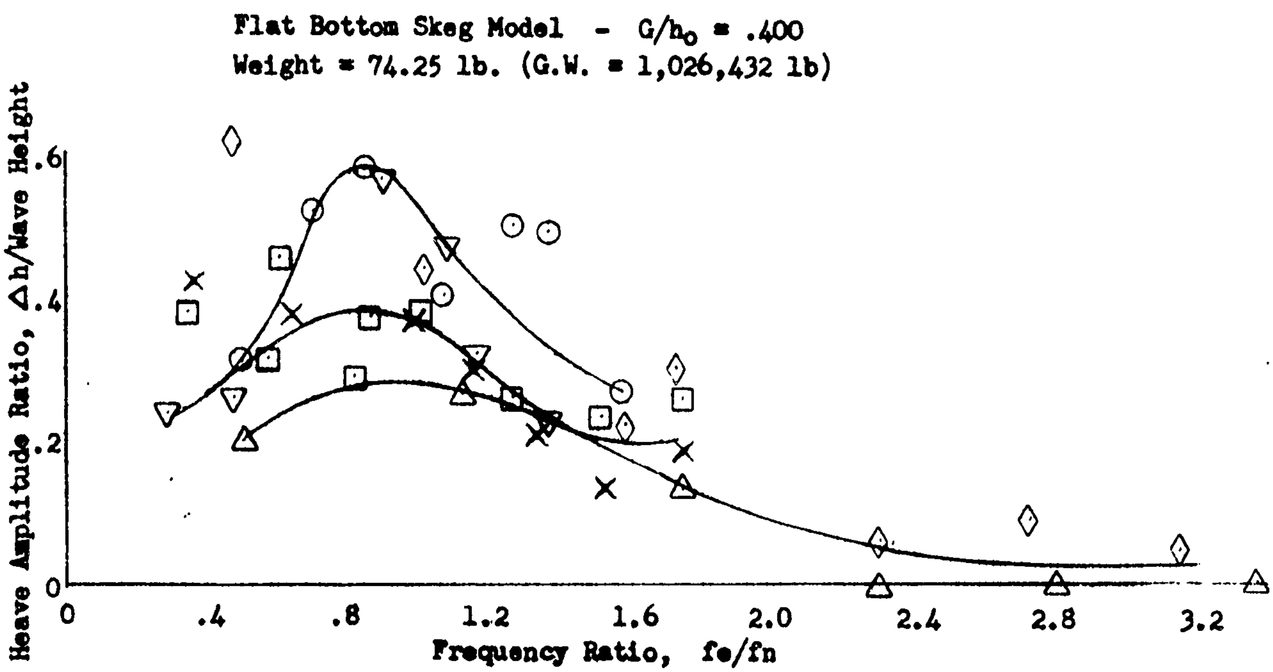


FIG. 14. HEAVE RESPONSE FOR BUSHIPS SKEG MODEL
(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.69	.334
△	.552	.334
▽	1.73	.843
×	1.275	.741
◊	.693	.741

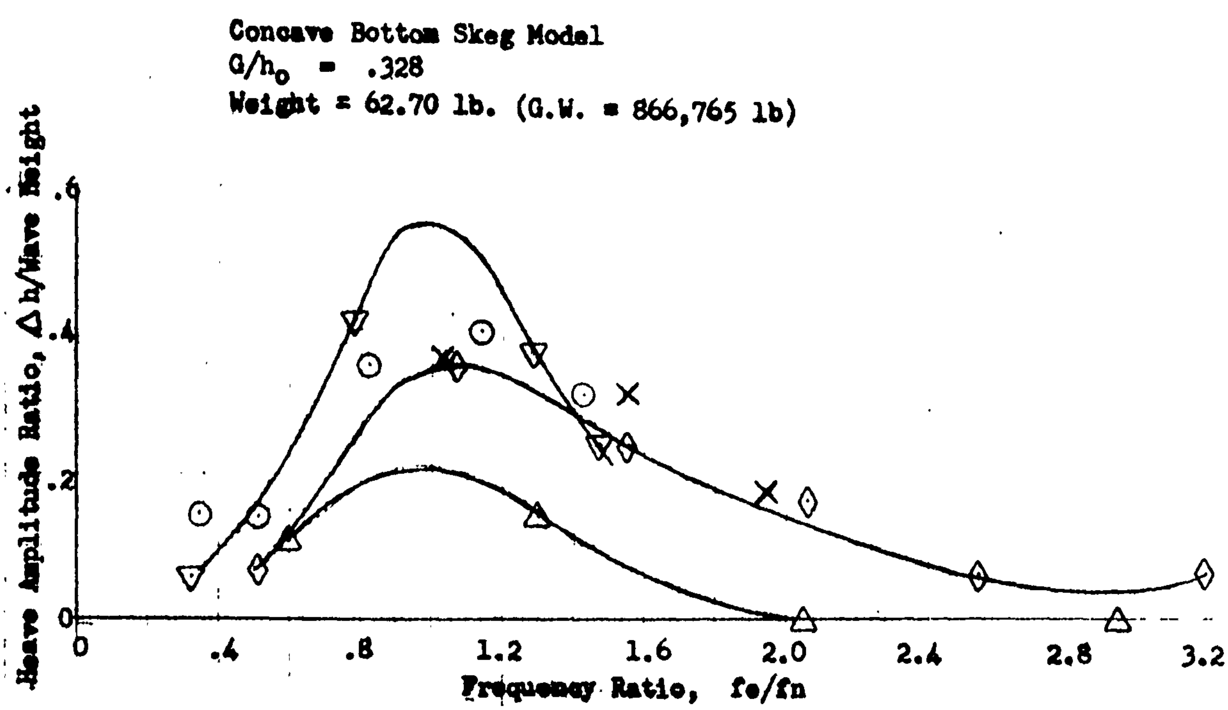


FIG. 14. HEAVE RESPONSE FOR BUSHIPS SKEG MODEL
(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.599	.349
⊡	1.353	.368
△	.560	.358
▽	1.656	.854
×	1.262	.765
◊	.634	.760

Flat Bottom Skeg Model
G/h_o = .333
Weight = 58.75 lb. (G.W. = 812,160 lb)

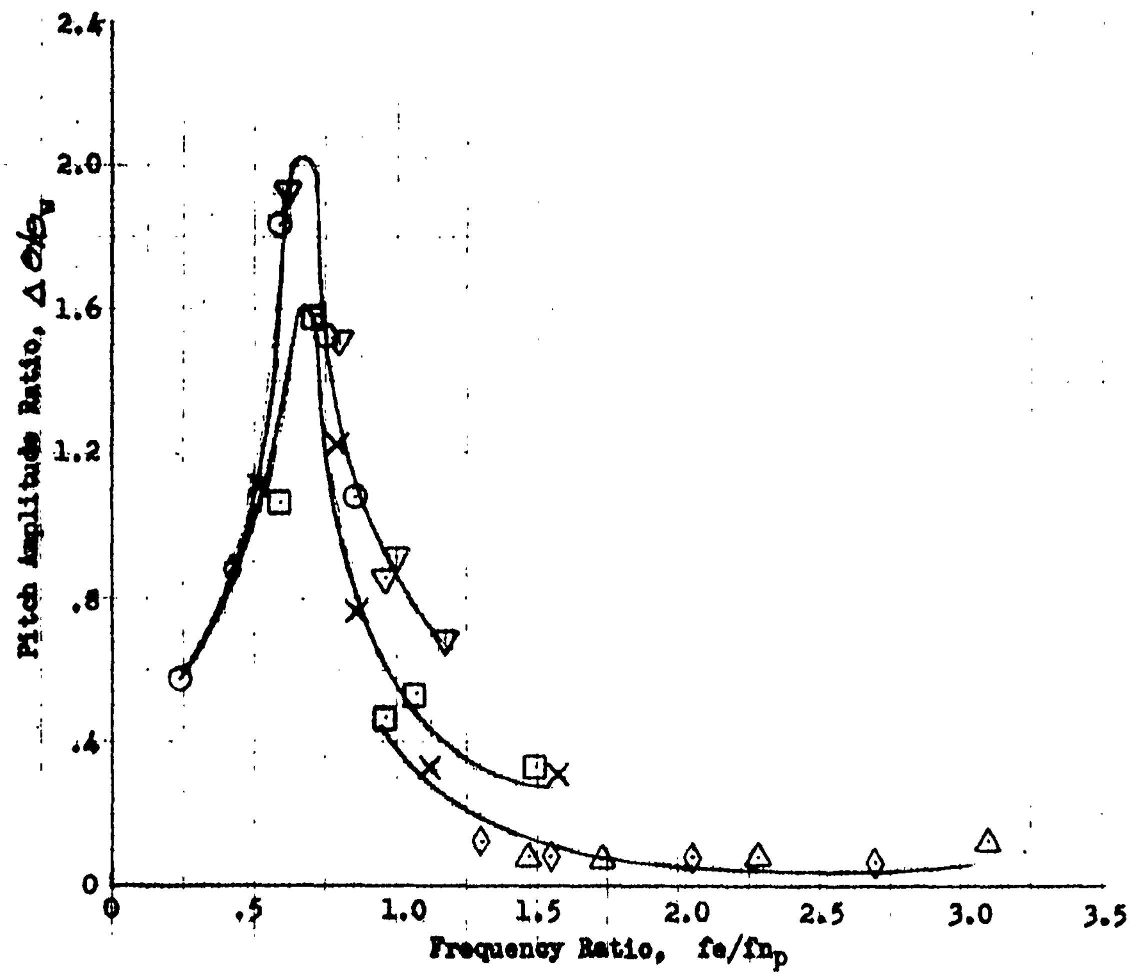


FIG. 15. PITCH RESPONSE FOR BUSHIPS SKEG MODEL

Symbol	λ/L	h_w/h_o
⊙	1.64	.402
⊡	1.319	.460
△	.565	.4375
▽	1.782	1.039
✕	1.289	.924
◇	.704	.698

Flat Bottom Skeg Model
G/h_o = .400

Weight = 74.25 lb. (G.W. = 1,026,432 lb)

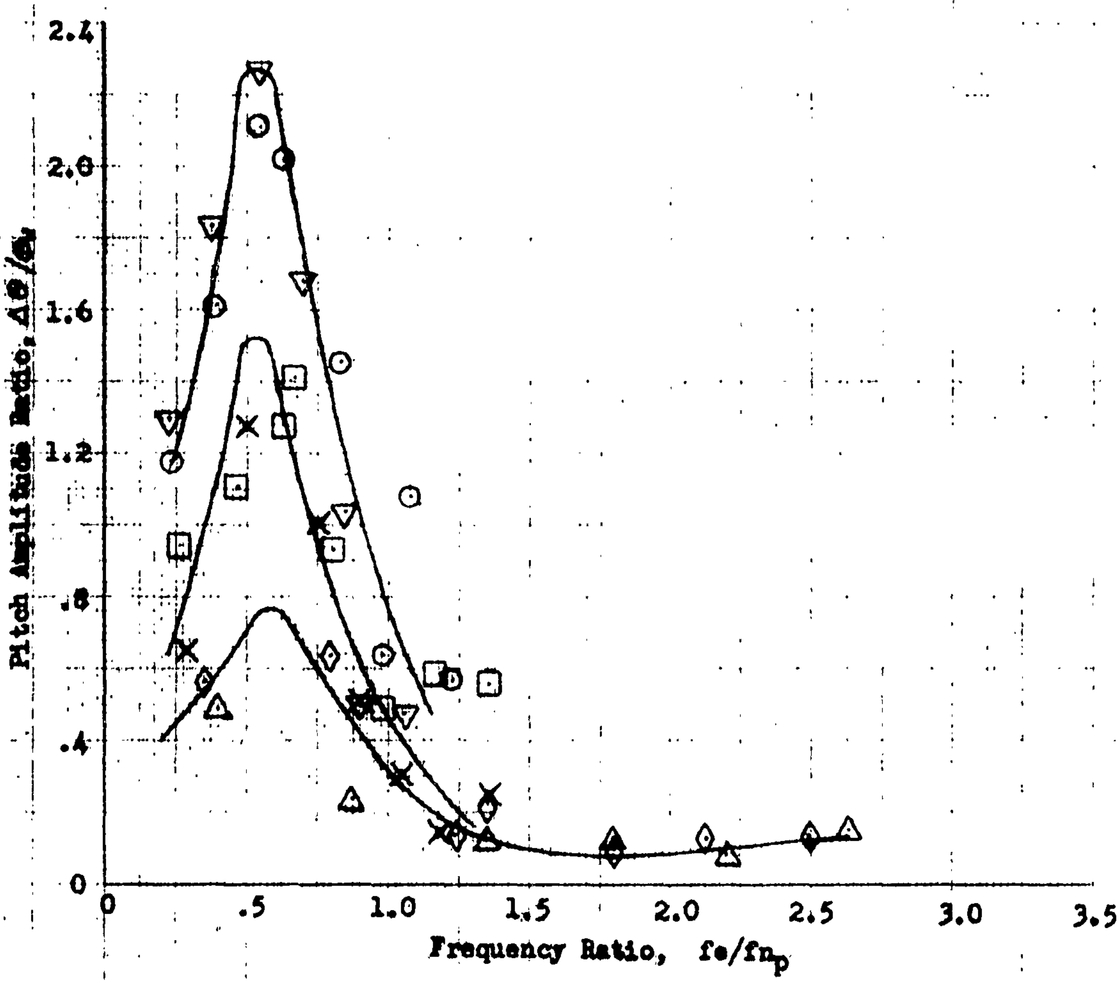


FIG. 15. PITCH RESPONSE FOR BUSHIPS SKEG MODEL
(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.69	.334
△	.552	.334
▽	1.73	.843
·	1.275	.741
◊	.693	.741

Concave Bottom Skeg Model
G/h_o = .328
Weight = 62.70 lb. (G.W. = 866,765 lb)

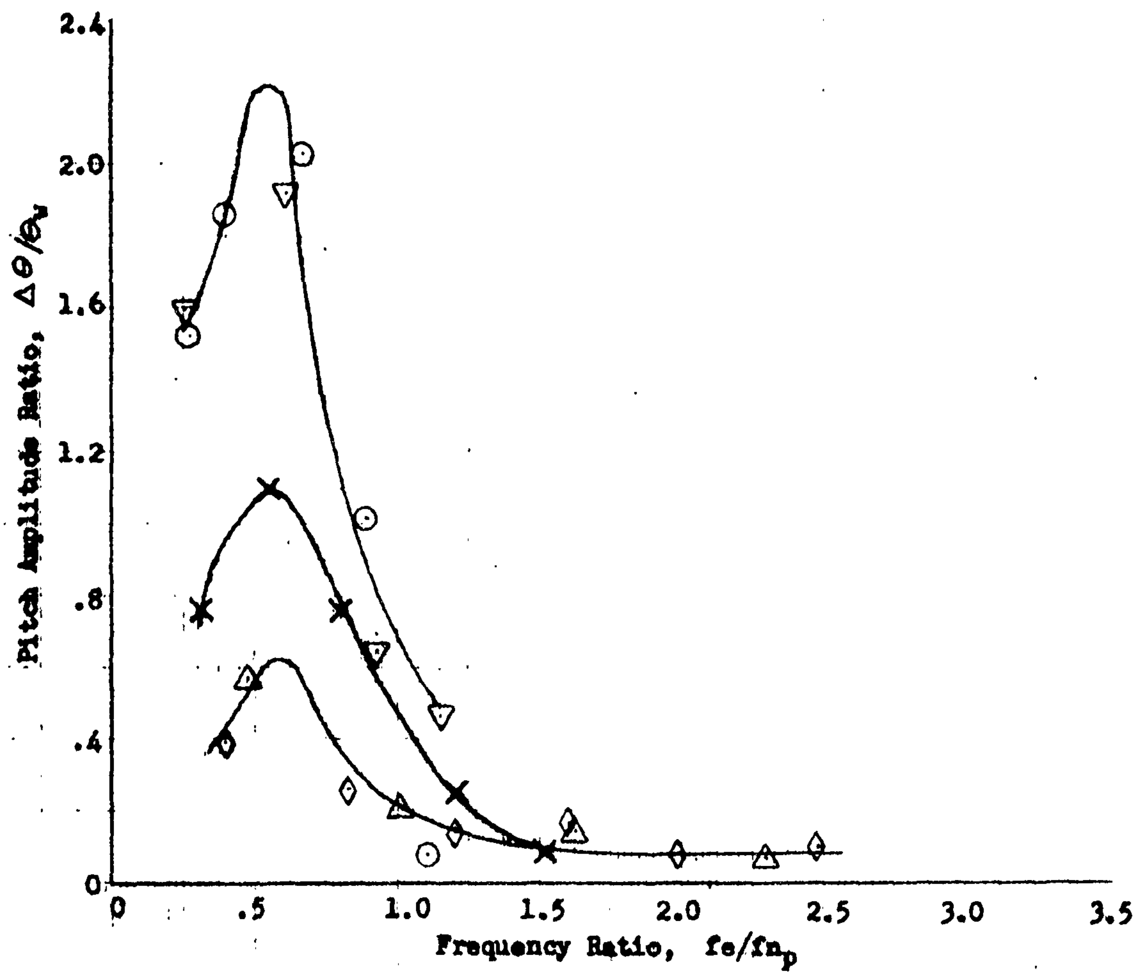


FIG. 15. PITCH RESPONSE FOR BUSHIPS SKEG MODEL
(Continued)

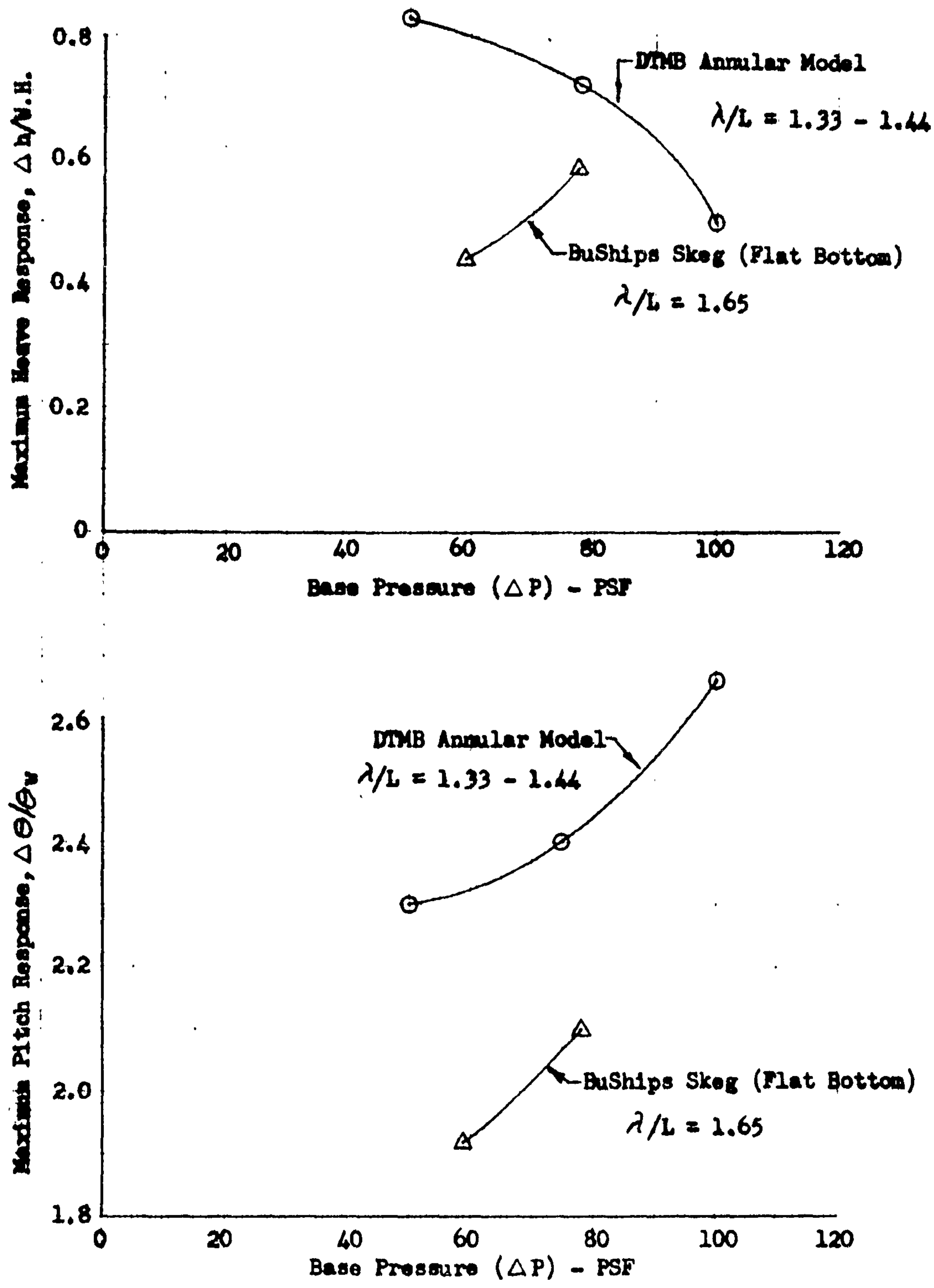


FIG. 16. MAXIMUM RESPONSE VS BASE PRESSURE

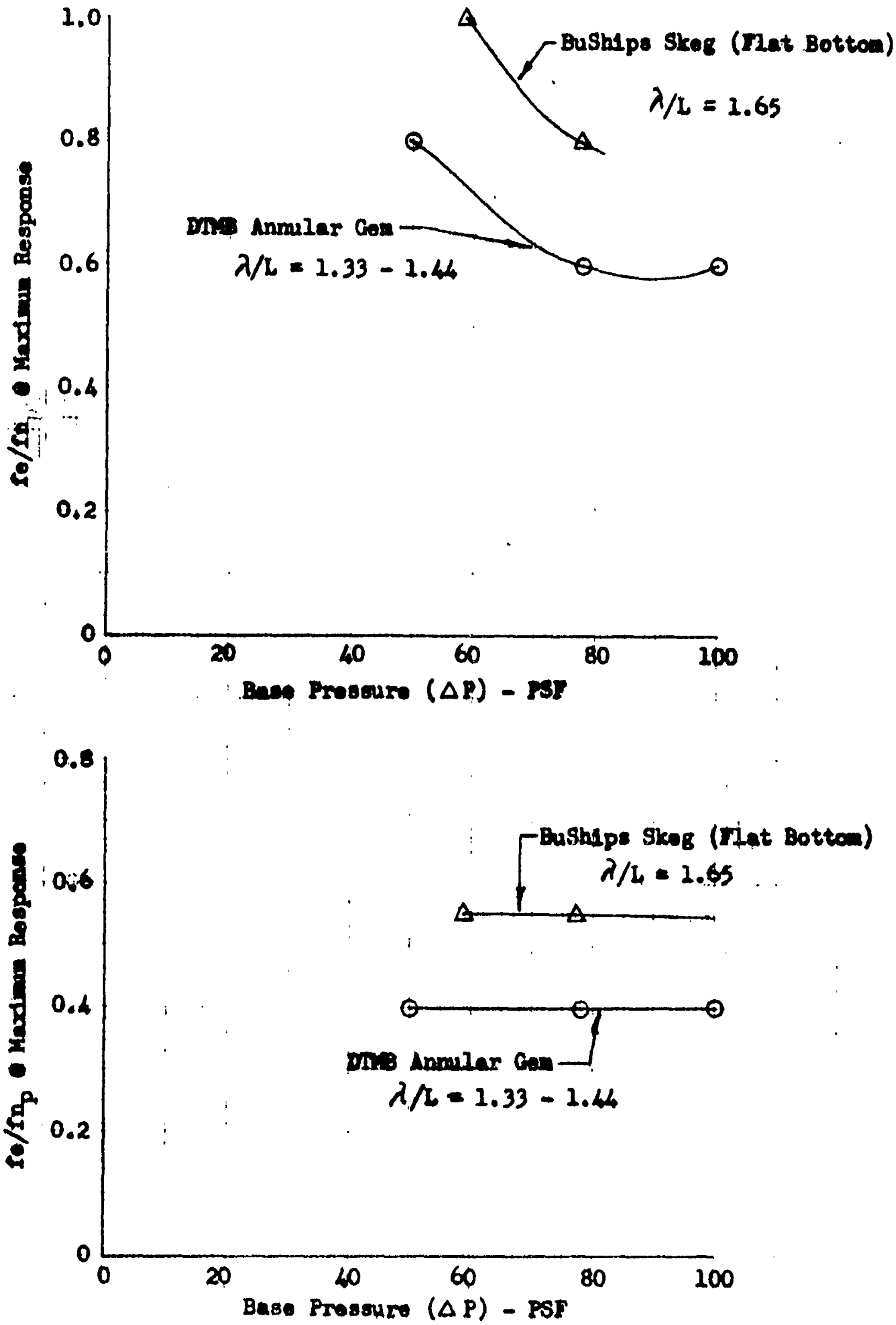


FIG. 17. CRITICAL FREQUENCY RATIO VS BASE PRESSURE

Symbol	λ/L	h_w/h_o
⊙	2.00	.984
⊡	1.31	.962
△	.558	.944
▽	1.771	1.550
×	1.328	1.250
◊	1.215	1.160

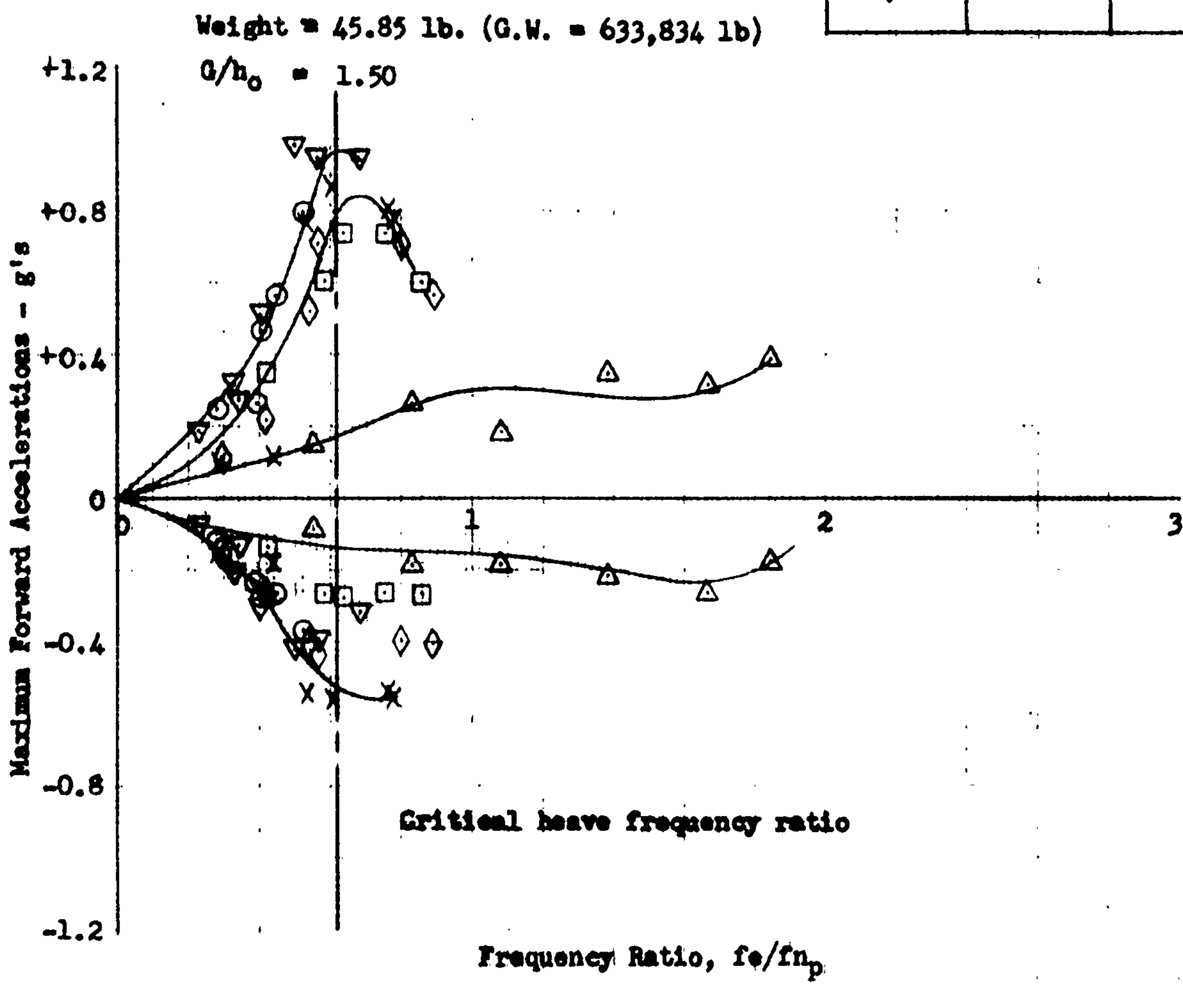


FIG. 18. FORWARD ACCELERATIONS FOR DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	1.614	1.612
⊡	1.440	1.166
△	1.362	1.720

Weight = 65.55 lb. (G.W. = 906,163 lb)

G/h_o = .960

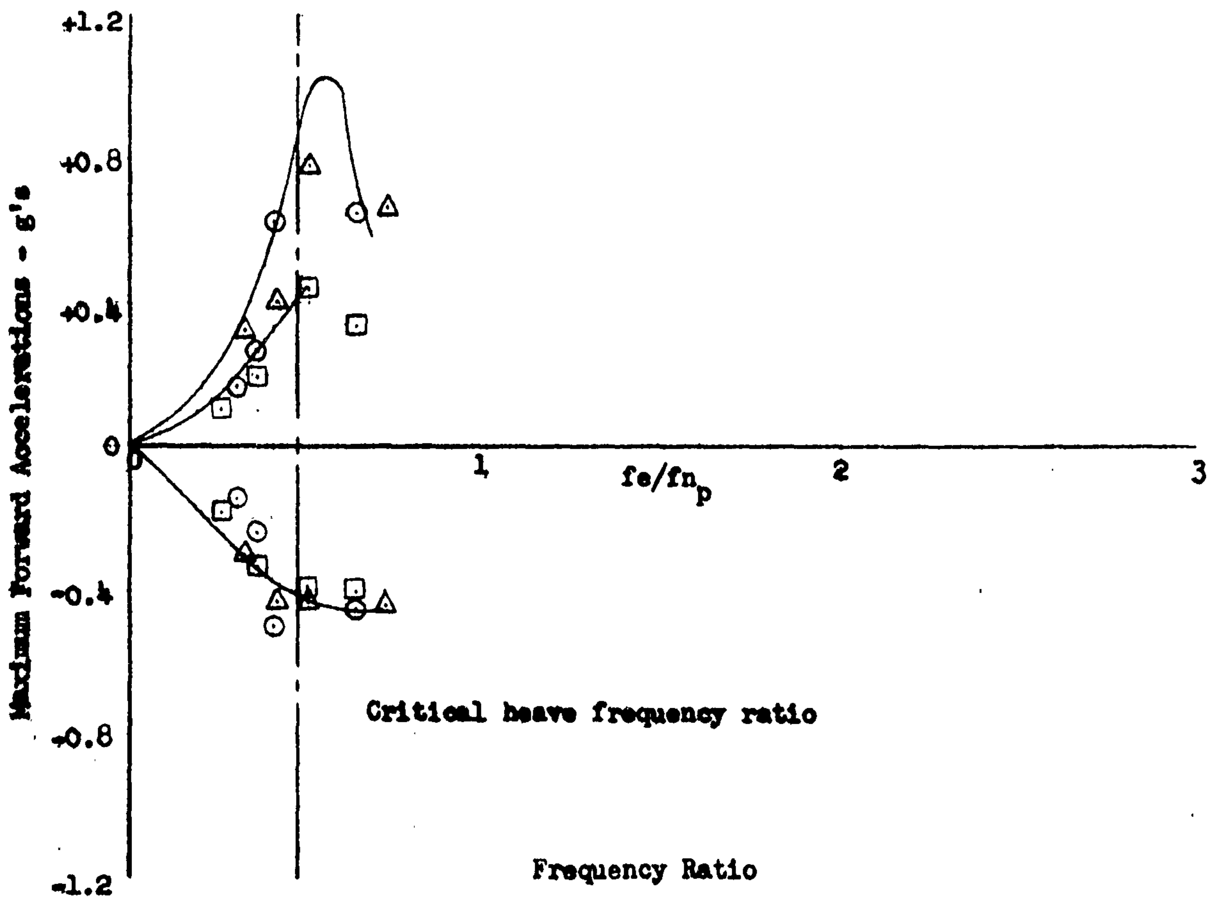


FIG. 18. FORWARD ACCELERATIONS FOR DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊡	1.438	1.294
△	.554	1.247

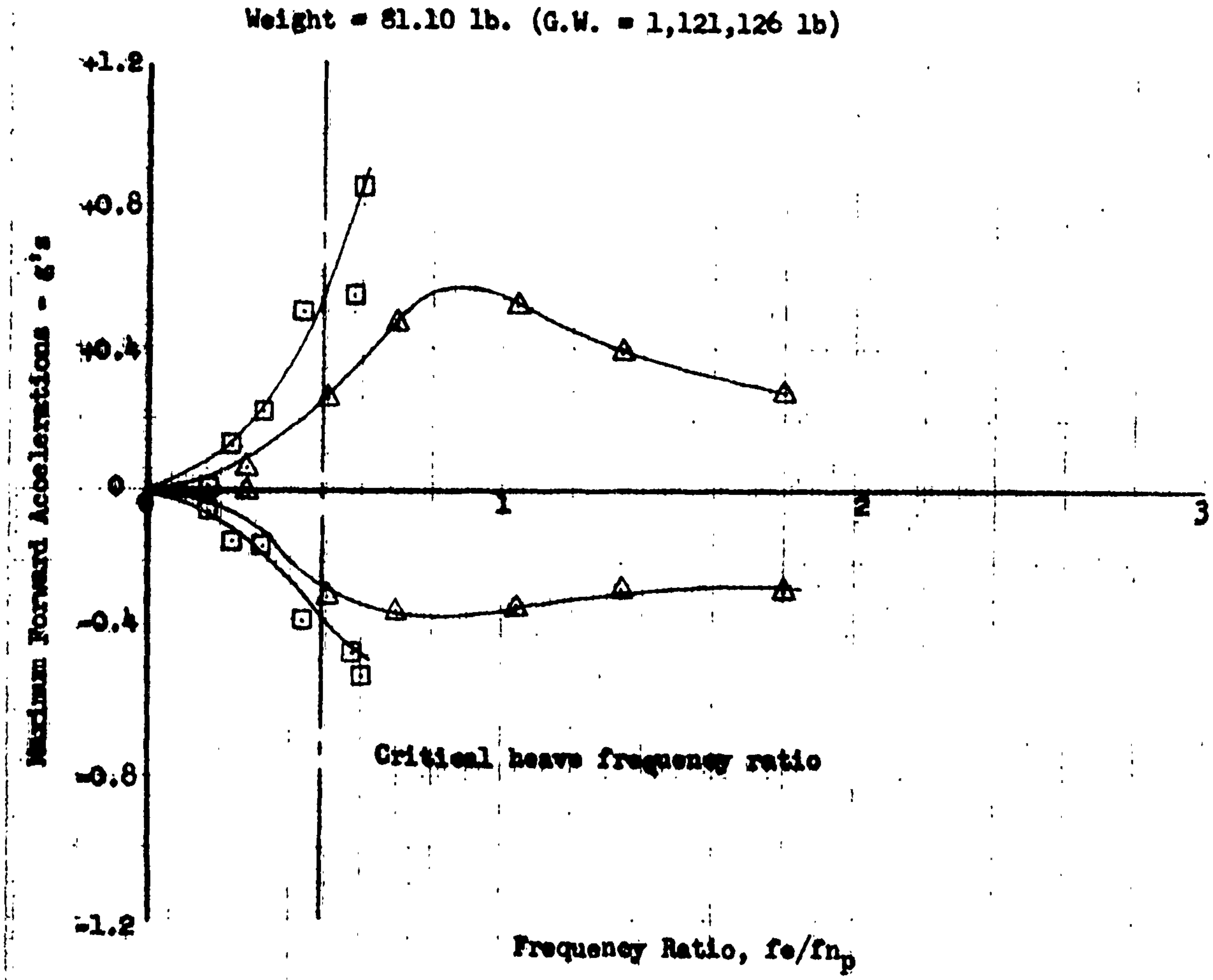


FIG. 18. FORWARD ACCELERATIONS FOR DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.599	.349
⊡	1.353	.368
△	.560	.358
▽	1.656	.854
×	1.262	.765
◊	.634	.760

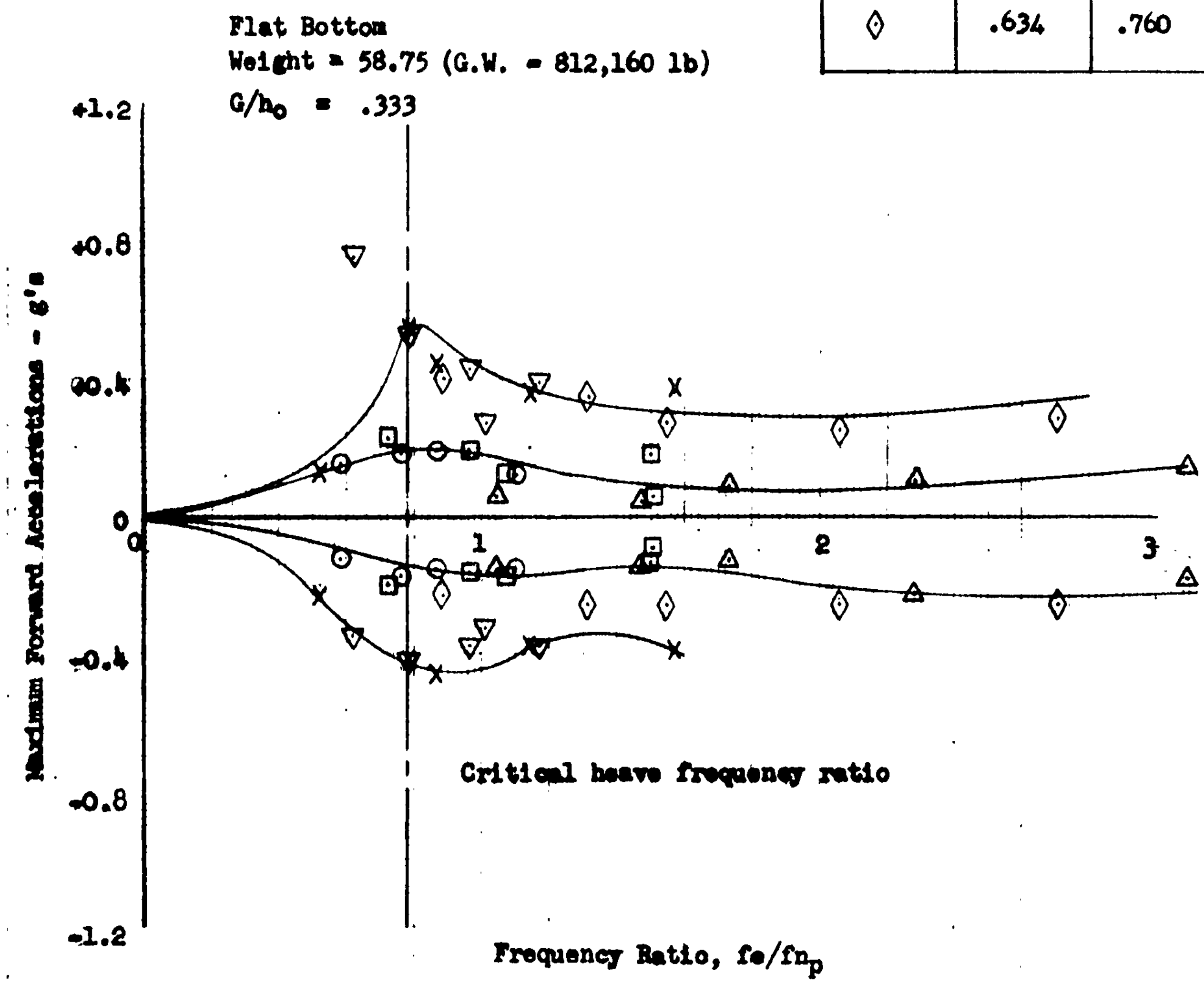


FIG. 19. FORWARD ACCELERATIONS FOR BUSHIPS SKEG MODEL

Symbol	λ/L	h_w/h_o
⊙	1.64	.402
⊡	1.319	.460
△	.565	.4375
▽	1.782	1.039
X	1.289	.924
◊	.704	.698

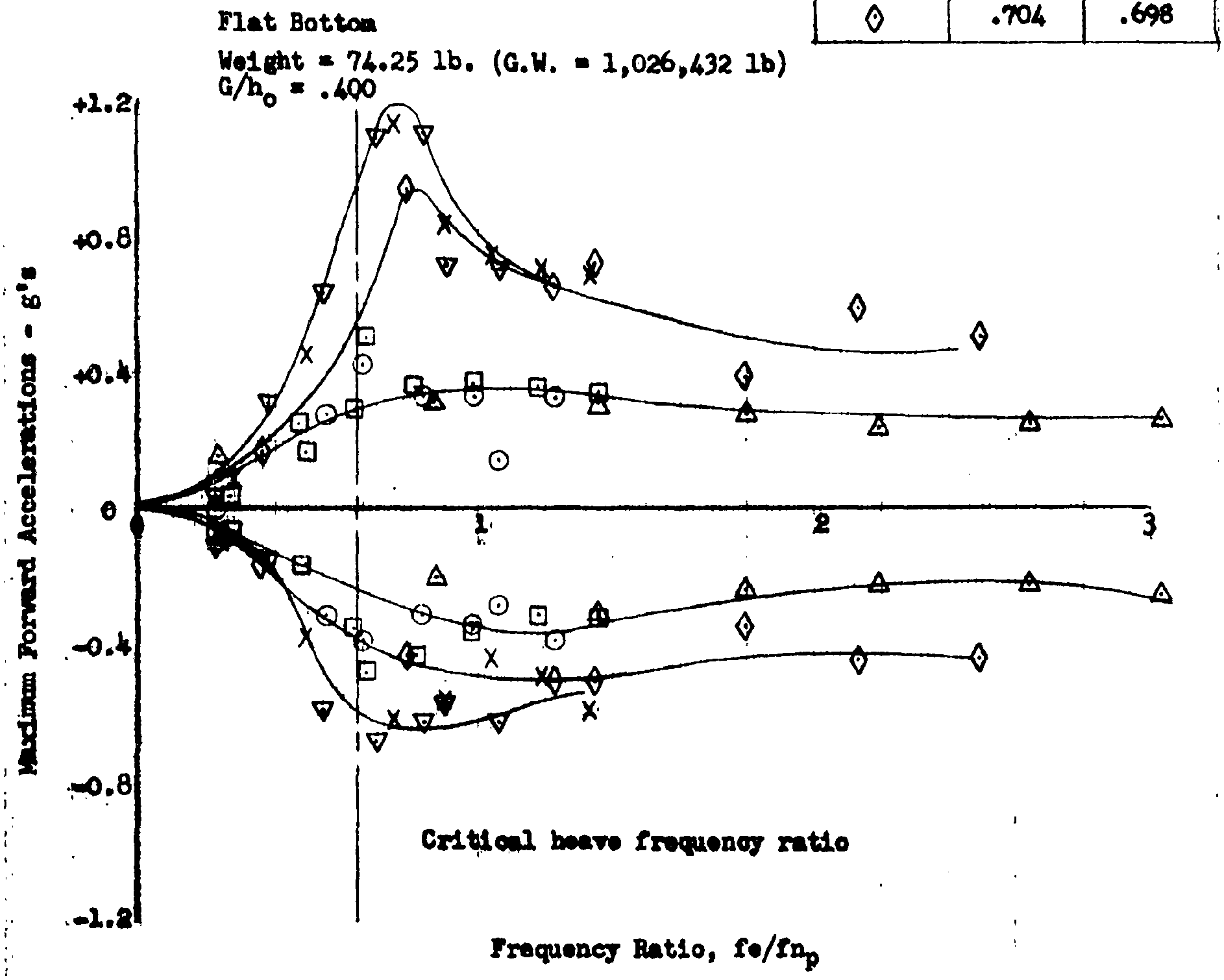


FIG. 19. FORWARD ACCELERATIONS FOR BUSHIPS SKEG MODEL (Continued)

Symbol	λ/L	h_w/h_o
⊙	1.69	.334
△	.552	.334
▽	1.73	.843
×	1.275	.741
◊	.693	.741

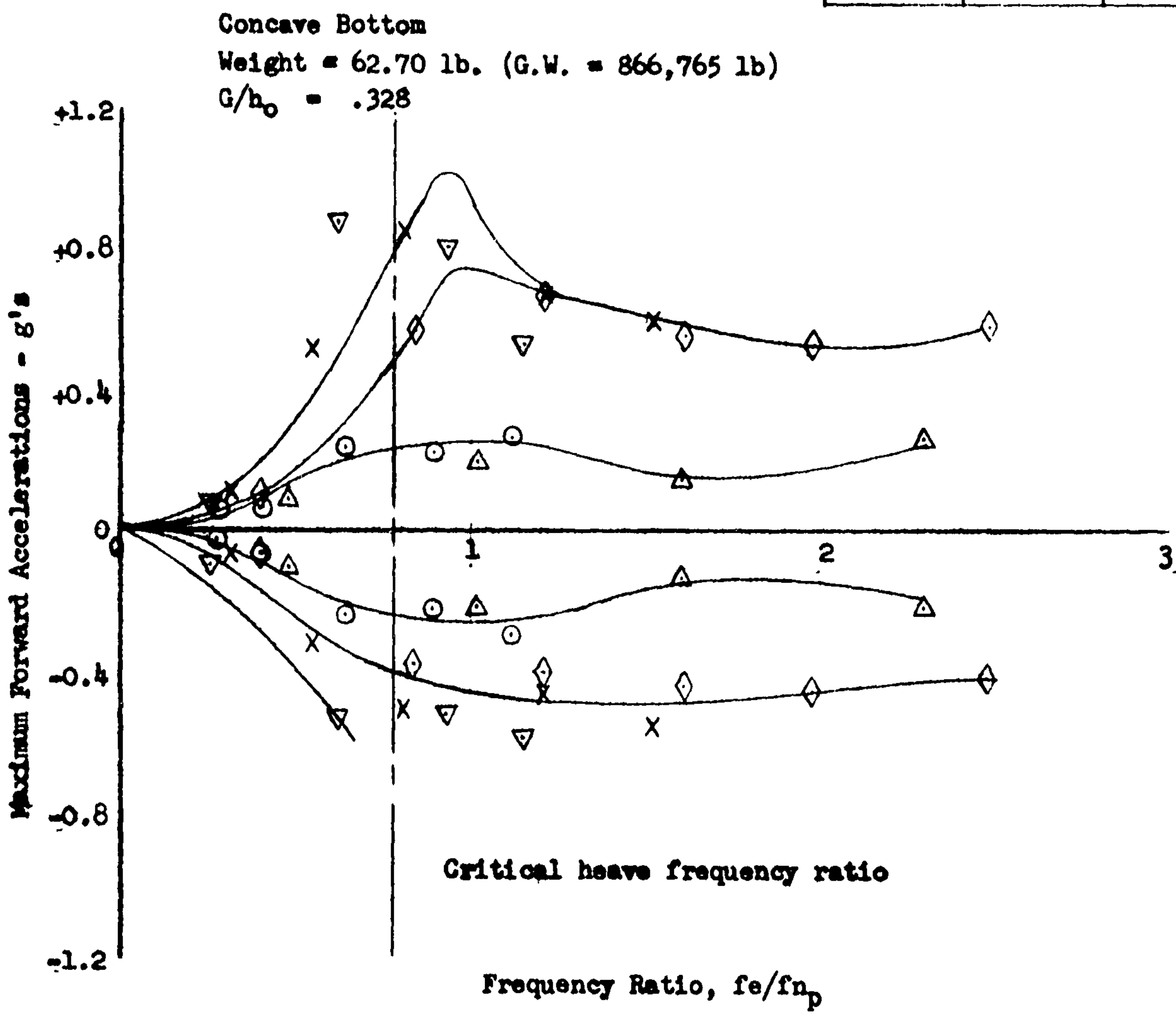


FIG. 19. FORWARD ACCELERATIONS FOR BUSHIPS SKEG MODEL
(Continued)

Model	Symbol	λ/L	h_w/h_o
45.85	⊙	2.00	.984
	⊡	1.31	.962
	△	0.558	.944
	▽	1.771	1.550
	×	1.328	1.250
	◊	1.215	1.160
65.55	⊙	1.614	1.612
	⊡	1.440	1.166
	△	1.362	1.720
81.10	⊡	1.438	1.294
	△	.554	1.247

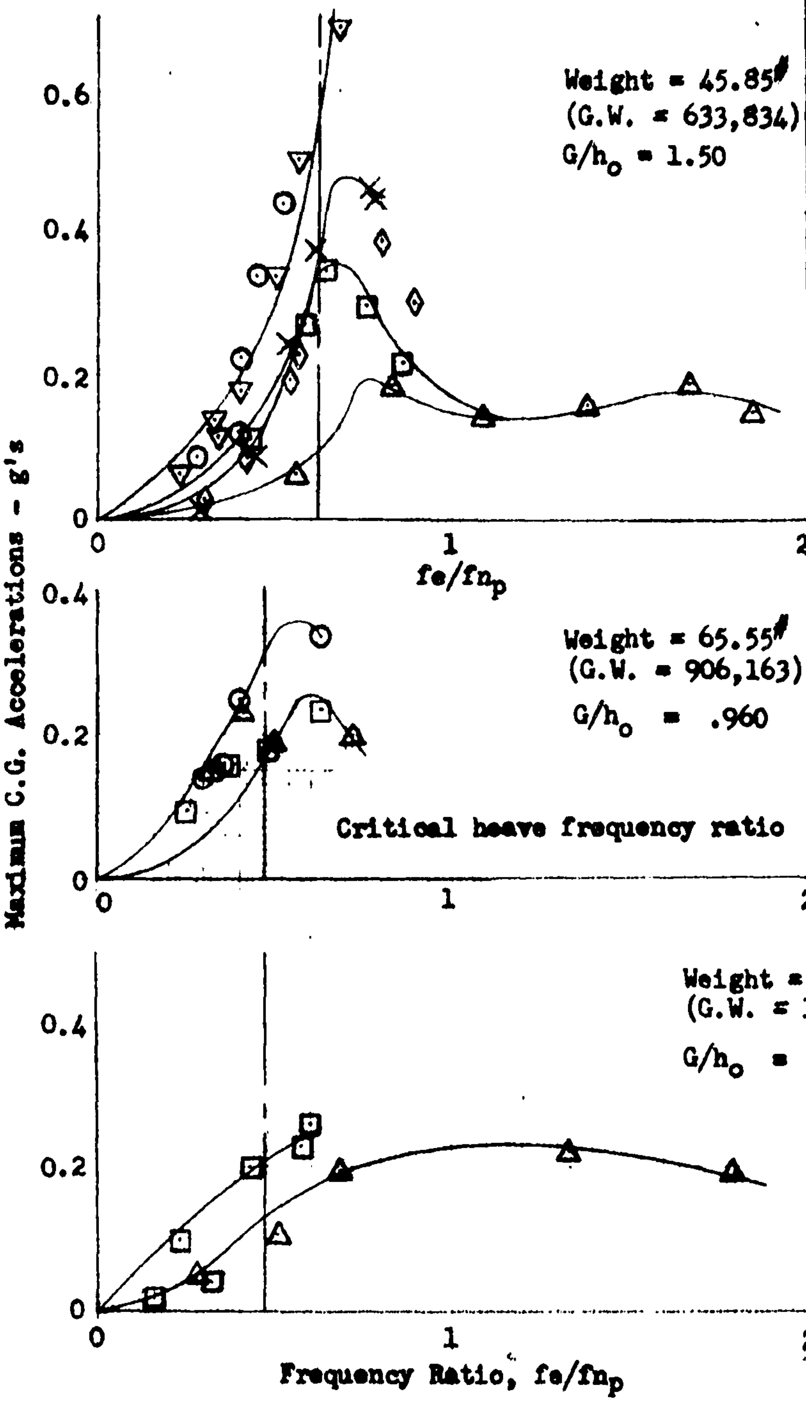


FIG. 20. C.G. ACCELERATIONS OVER WAVES FOR DTMB ANNULAR GEM

Model	Symbol	λ /L	h_w/h_o
58.75	⊙	1.599	.349
	⊡	1.353	.368
	△	.560	.358
	▽	1.656	.854
	×	1.262	.765
	◊	.634	.760
62.70	⊙	1.69	.334
	▽	1.73	.843
	×	1.275	.741
	◊	.693	.741
74.25	⊙	1.64	.402
	⊡	1.319	.460
	▽	1.782	1.039
	×	1.289	.924
	◊	.704	.698

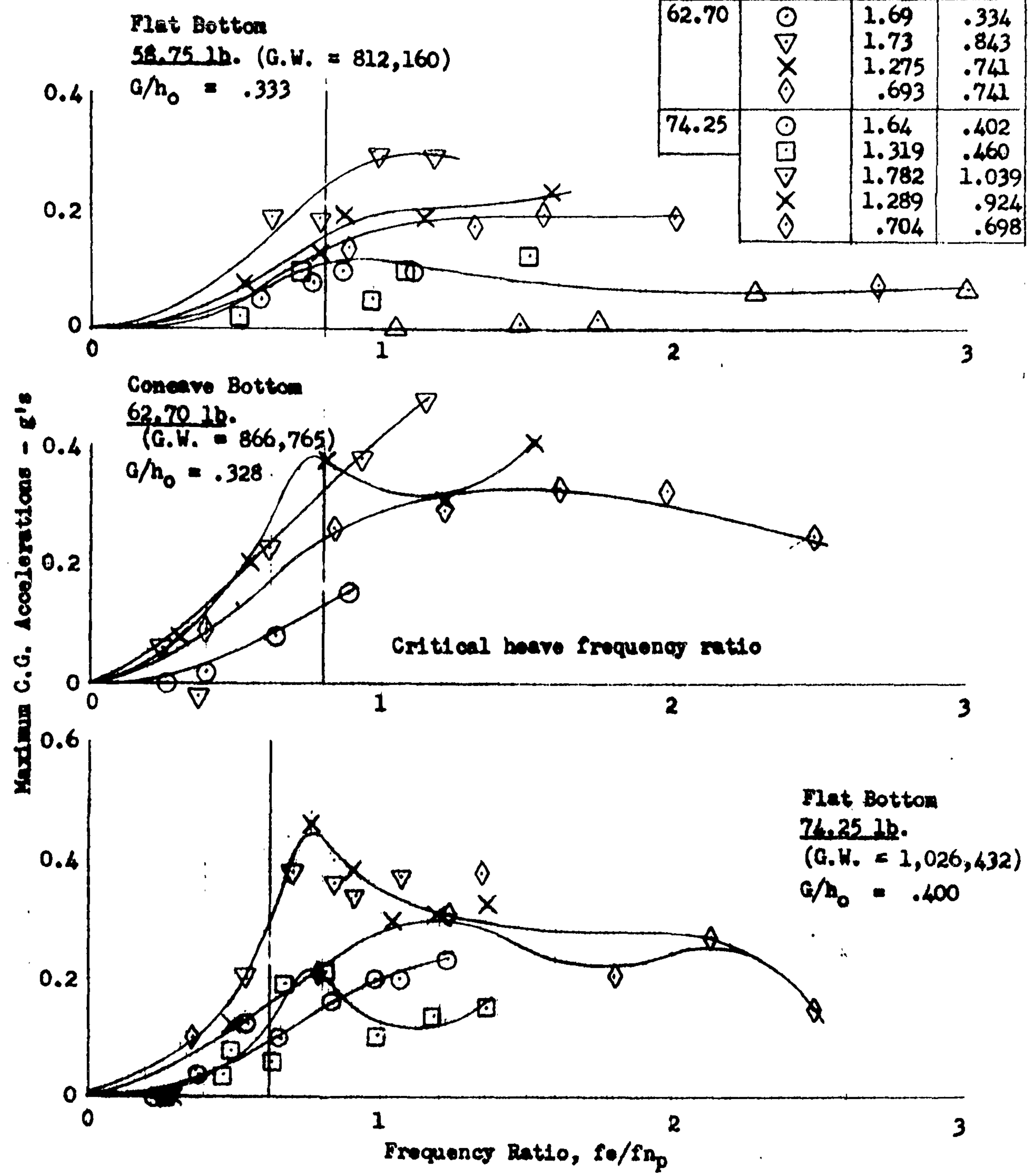
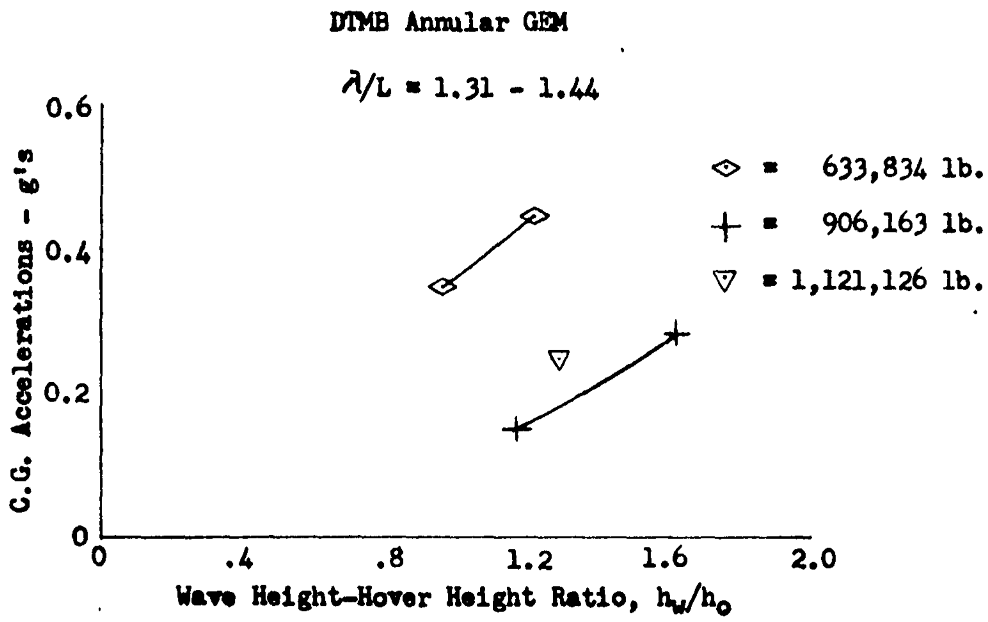


FIG. 20. C.G. ACCELERATIONS OVER WAVES FOR BUSHIPS SKEG MODEL



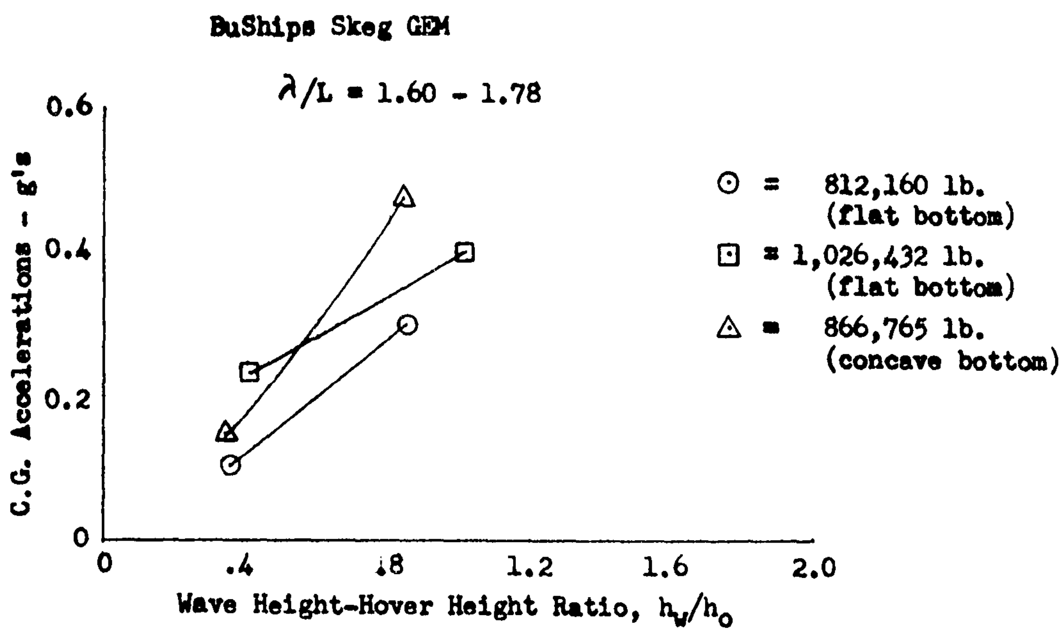


FIG. 21. C.G. ACCELERATION VS WAVE HEIGHT

Symbol	λ /L	h_w/h_o
⊙	2.00	.984
⊡	1.31	.962
△	.558	.944
▽	1.771	1.550
×	1.328	1.250
◊	1.215	1.160

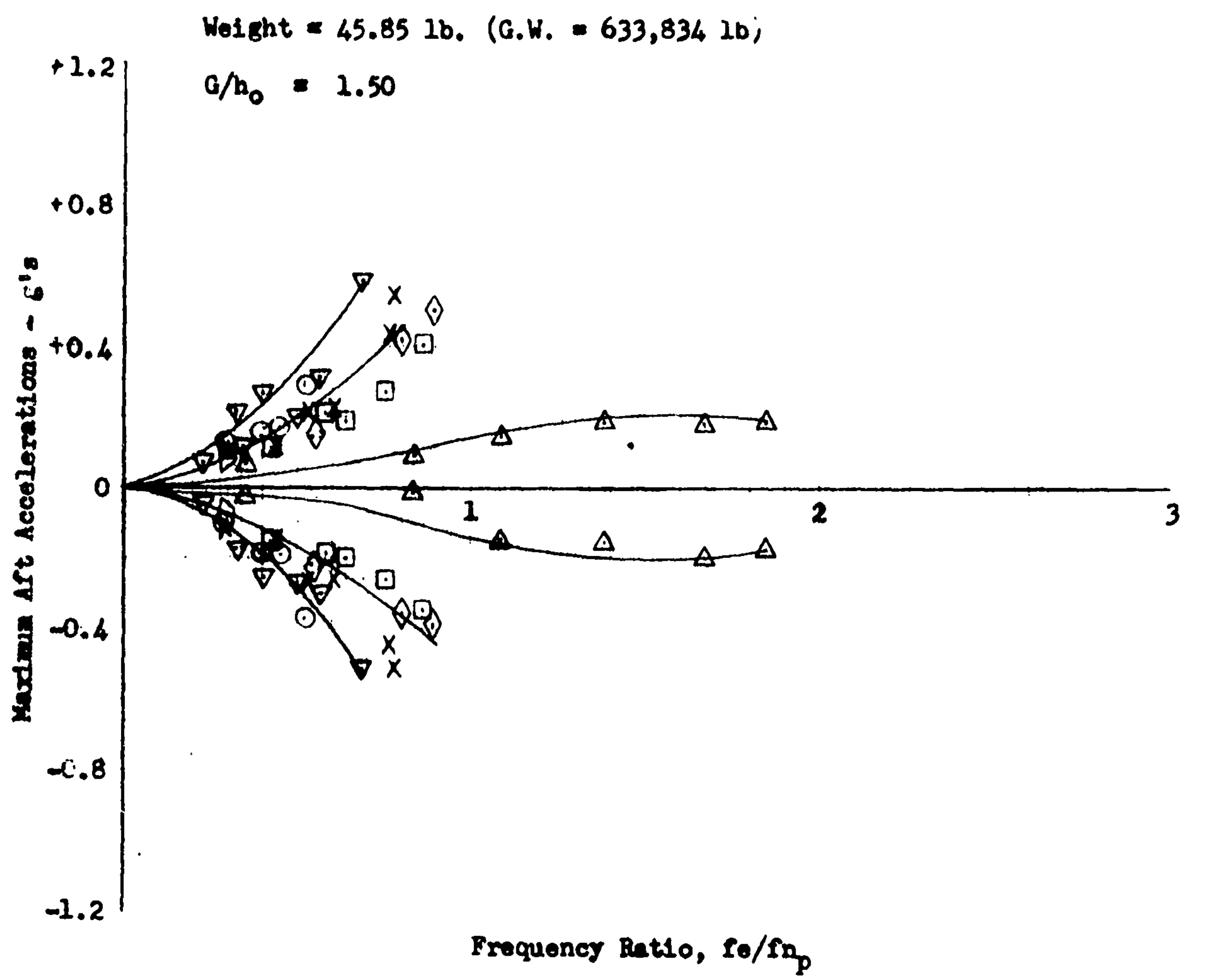


FIG. 22. AFT ACCELERATIONS OVER WAVES FOR DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	1.614	1.612
⊡	1.440	1.166
△	1.362	1.720

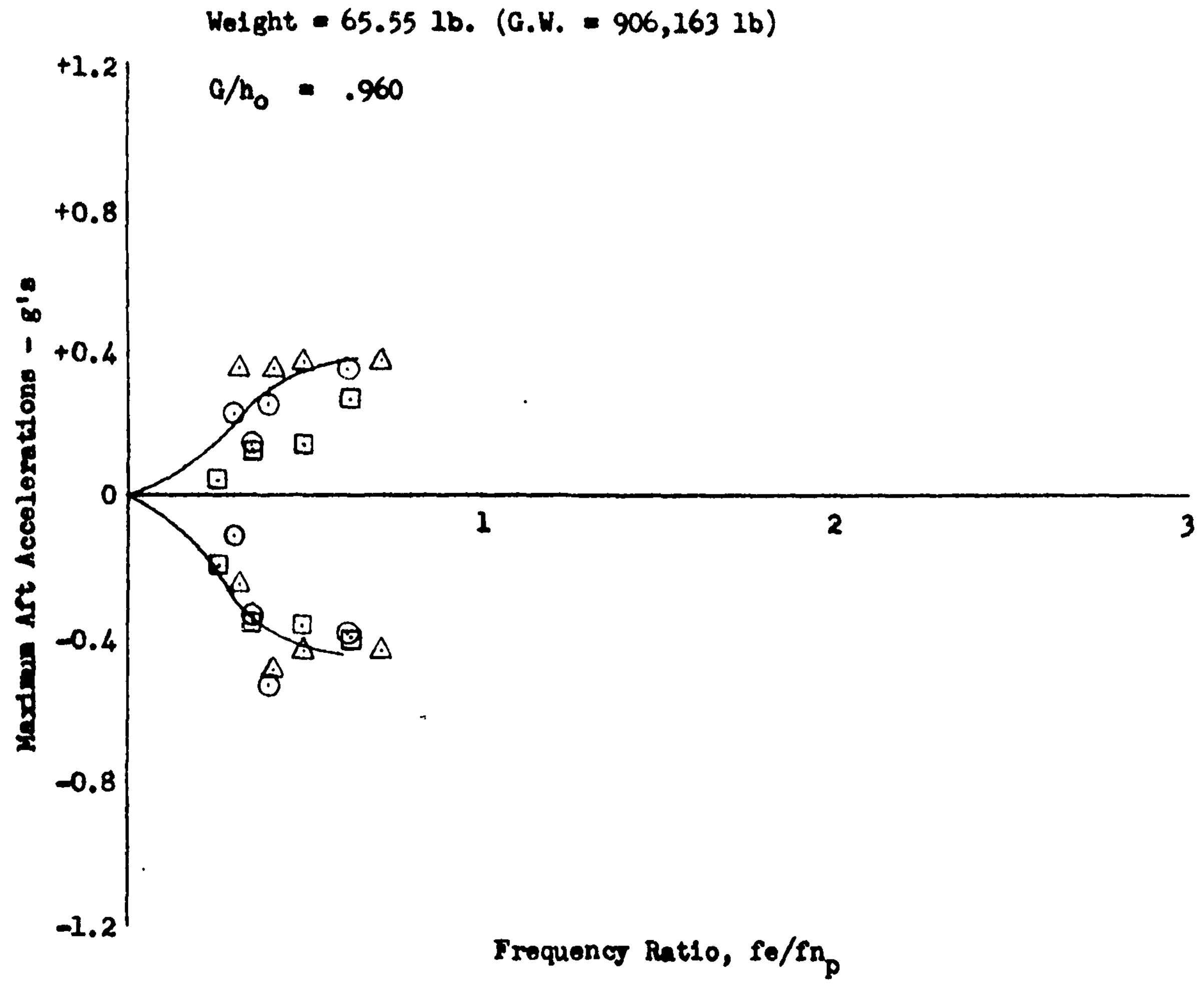


FIG. 22. AFT ACCELERATIONS OVER WAVES FOR DTMB ANNULAR GEM
(Continued)

Symbol	λ/L	h_w/h_o
⊡	1.438	1.294
△	.554	1.247

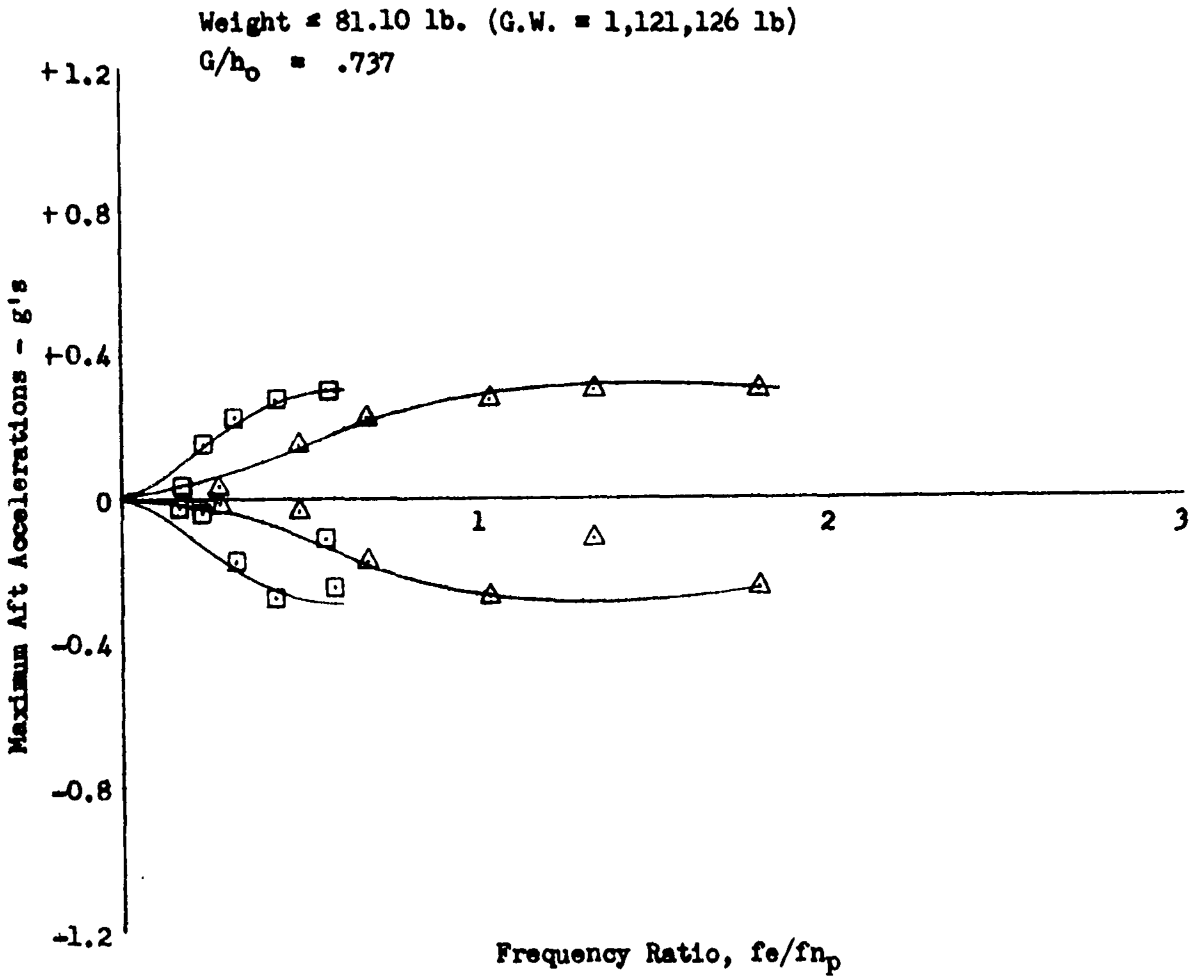


FIG. 22. AFT ACCELERATIONS OVER WAVES FOR DTMB ANNULAR GEM

Symbol	λ/L	h_w/h_o
⊙	1.64	.402
⊡	1.319	.460
△	.565	.4375
▽	1.782	1.039
×	1.289	.924
◊	.704	.698

Flat Bottom
Weight = 74.25 lb. (G.W. = 1,026,432 lb)
G/h_o = .400

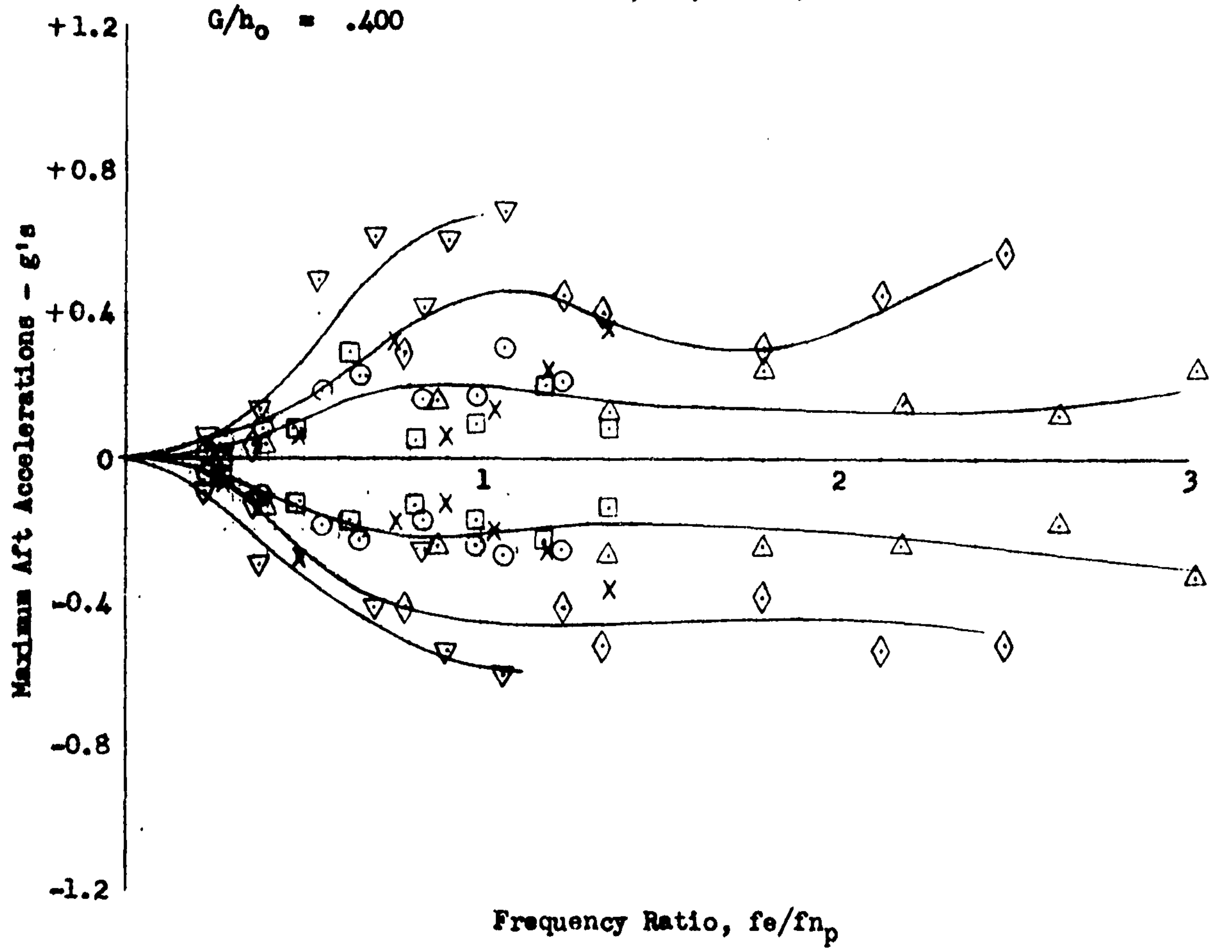


FIG. 23. AFT ACCELERATIONS OVER WAVES FOR BUSHIPS SKEG MODEL

Symbol	λ/L	h_w/h_o
⊙	1.599	.349
⊡	1.353	.368
△	.560	.358
▽	1.656	.854
X	1.262	.765
◊	.634	.760

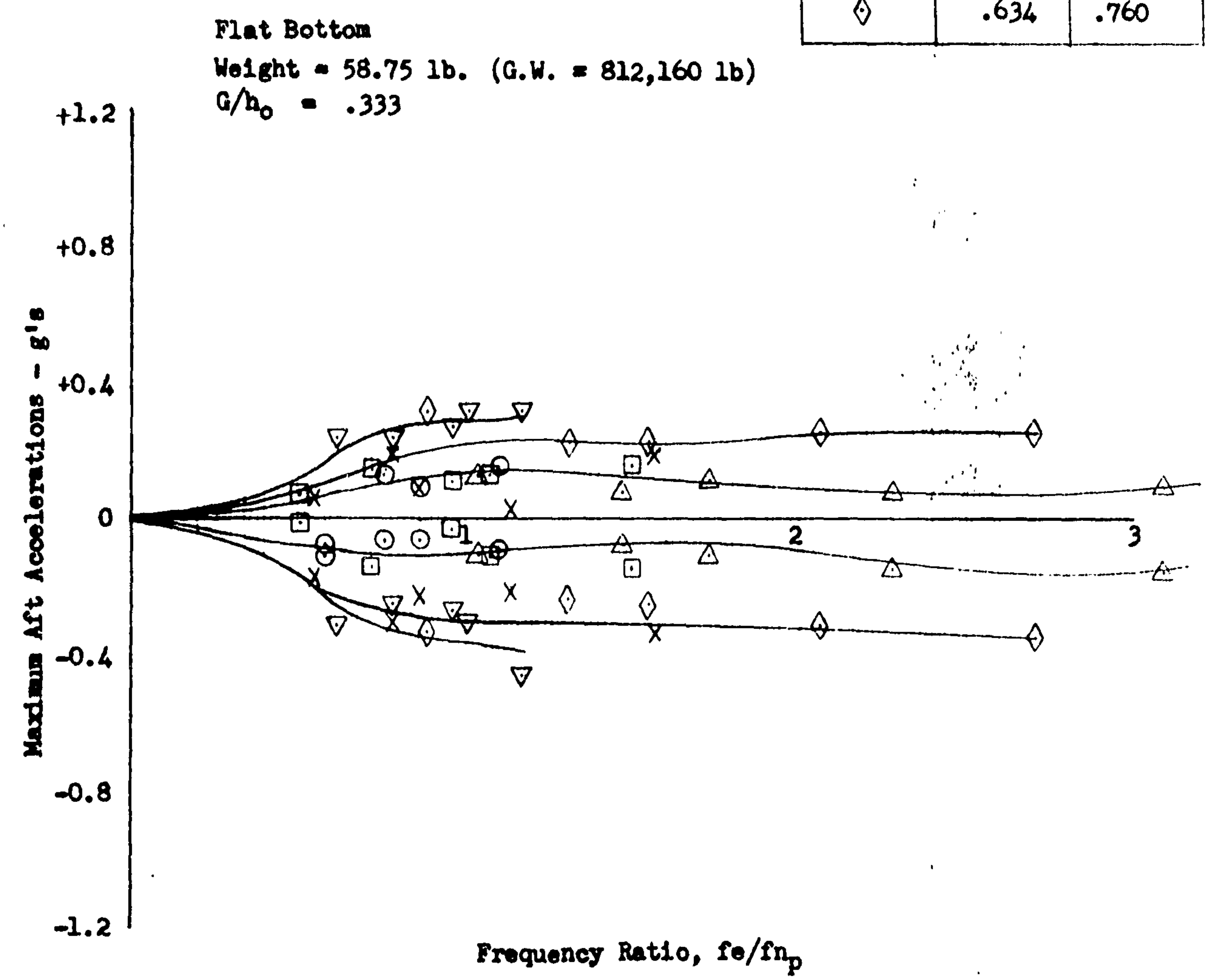


FIG. 23. AFT ACCELERATIONS OVER WAVES FOR BUSHIPS SKEG MODEL

(Continued)

Symbol	λ/L	h_w/h_o
⊙	1.69	.334
△	.552	.334
▽	1.73	.843
×	1.275	.741
◊	.693	.741

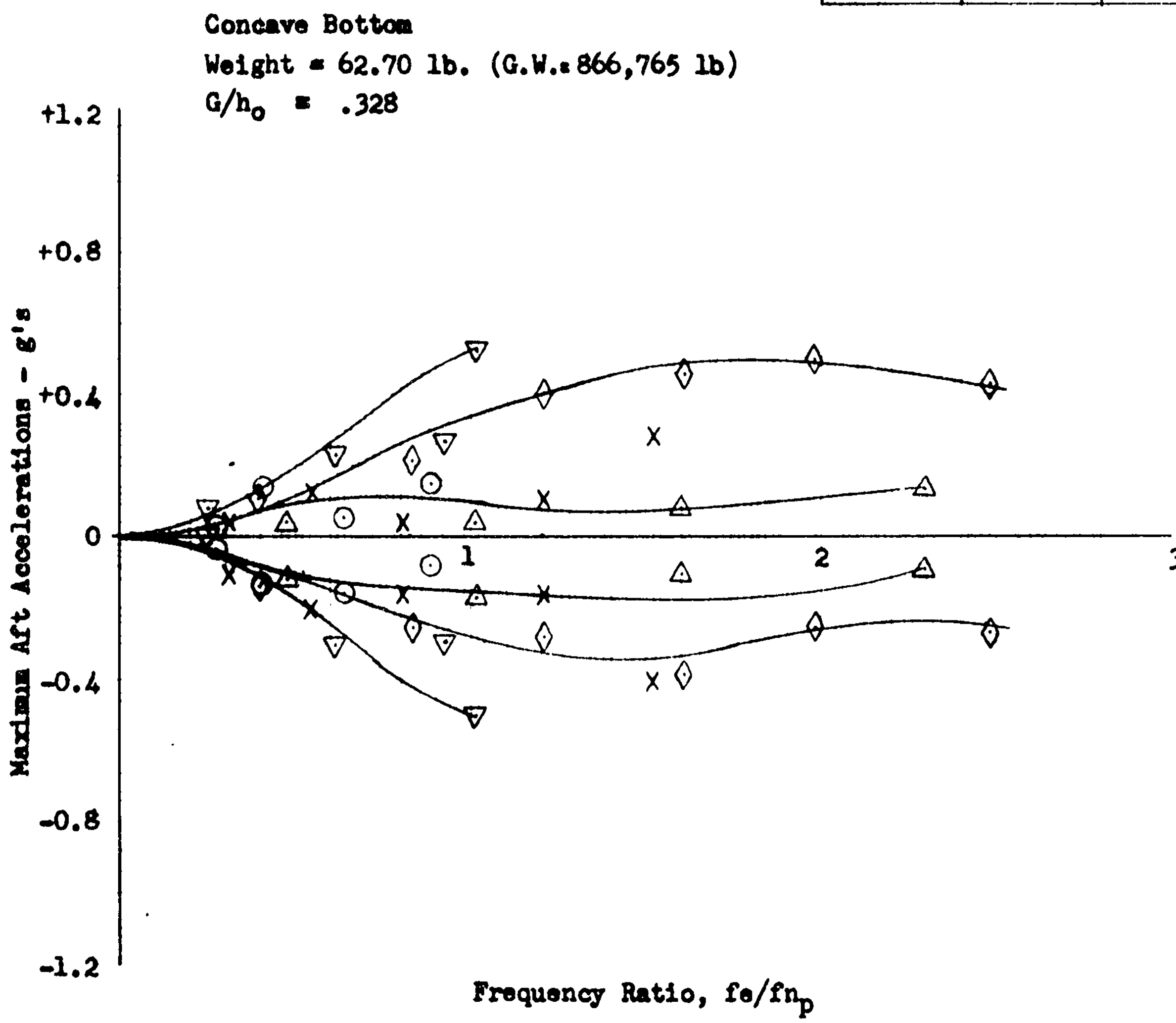


FIG. 23. AFT ACCELERATIONS OVER WAVES FOR BUSHIPS SKEG MODEL
(Continued)

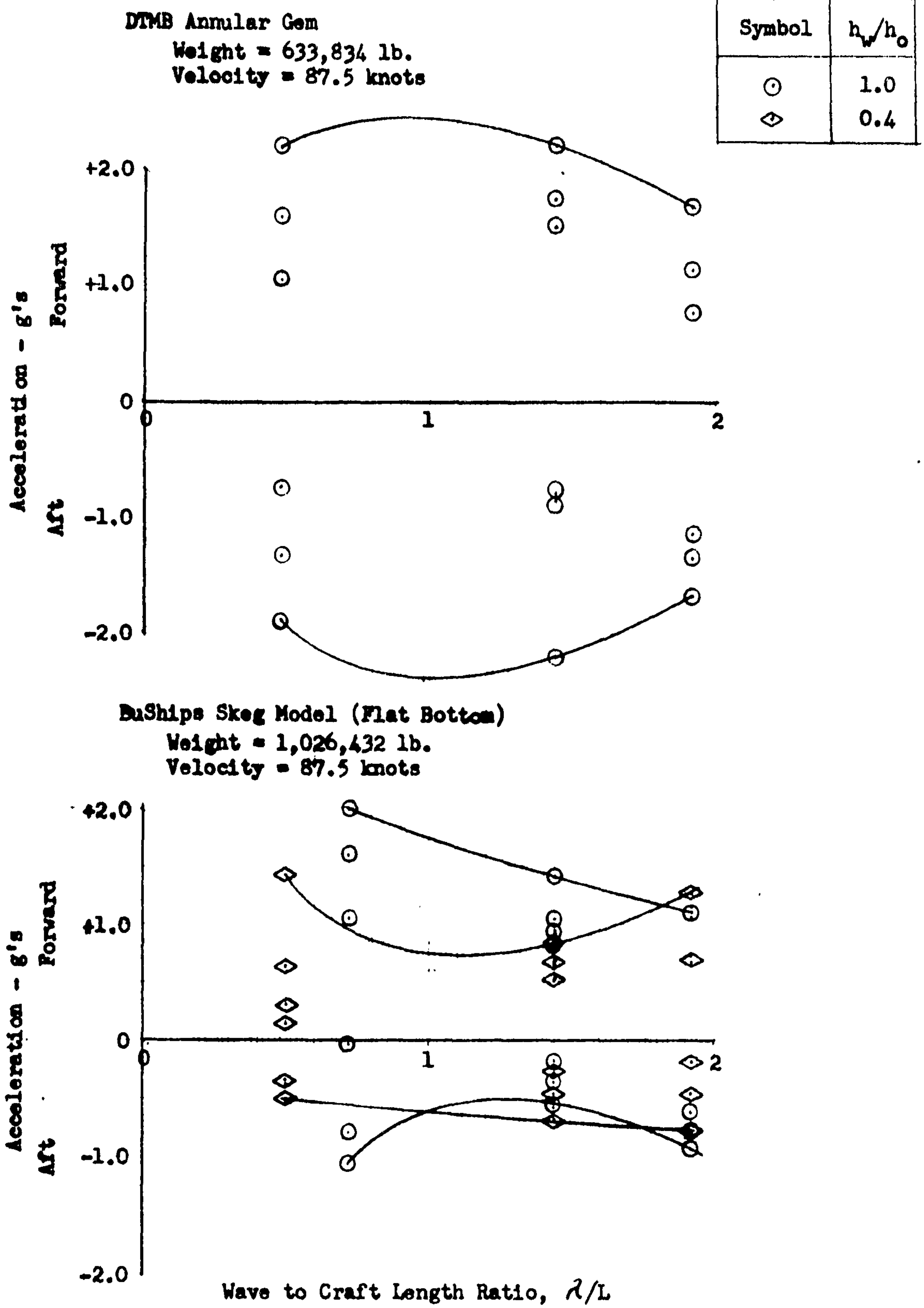


FIG. 24. MAXIMUM IMPACT ACCELERATION IN WAVES DUE TO POWER FAILURE

TABLE II

MAXIMUM IMPACT ACCELERATIONS IN WAVES DUE TO POWER FAILURE

Gross Weight: DTMB Annular Jet GEM - 633,834 lb.
BUSHIPS Skeg Model - 1,026,432 lb.

Velocity: 87.50 knots

/L	h_w/h_o	Forward Accel. g's	Aft Accel. g's	λ/L	h_w/h_o	Forward Accel. g's	Aft Accel. g's
[illegible]	1.0	2.08	-1.89	.72	1.0	1.04	-0.11
		1.05	-1.80			1.60	-0.79
		1.59	-0.13	.72	1.0	1.98	-0.05
.48	1.0	1.36	-0.74				
				1.44	1.0	0.95	-0.37
1.44	1.0	1.75	-0.80			0.92	-0.57
		2.08	-0.86			0.81	-0.17
1.44	1.0	1.51	-2.08			1.41	-0.52
				1.44	1.0	1.04	-0.52
1.92	1.0	1.14	-1.34				
		0.77	-1.14	1.92	1.0	1.06	-0.62
1.92	1.0	1.68	-1.67			1.10	-0.77
				1.92	1.0	1.15	-0.93
				.48	0.4	0.63	-0.39
						0.14	-0.51
						0.31	-0.33
				.48	0.4	1.41	-0.38
				1.44	0.4	0.51	-0.69
						0.65	-0.26
						0.525	-0.17
						0.805	-0.24
						0.805	-0.46
						0.68	-0.29
				1.44	0.4	0.82	-0.16
				1.92	0.4	1.27	-0.18
						0.74	-0.46
				1.92	0.4	0.68	-0.77

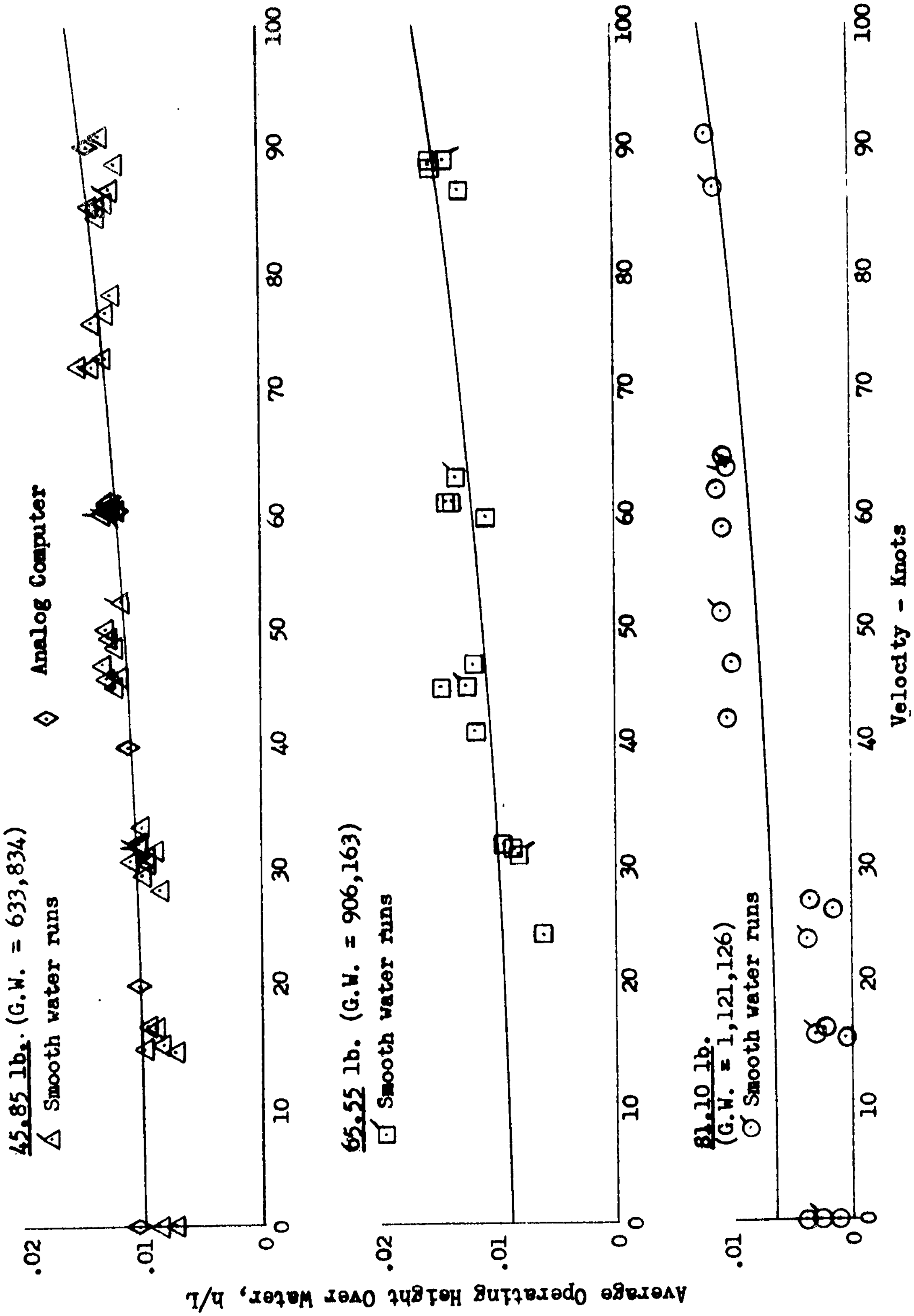


FIG. 25. AVERAGE OPERATING HEIGHT FOR DTMB ANNULAR JET MODEL

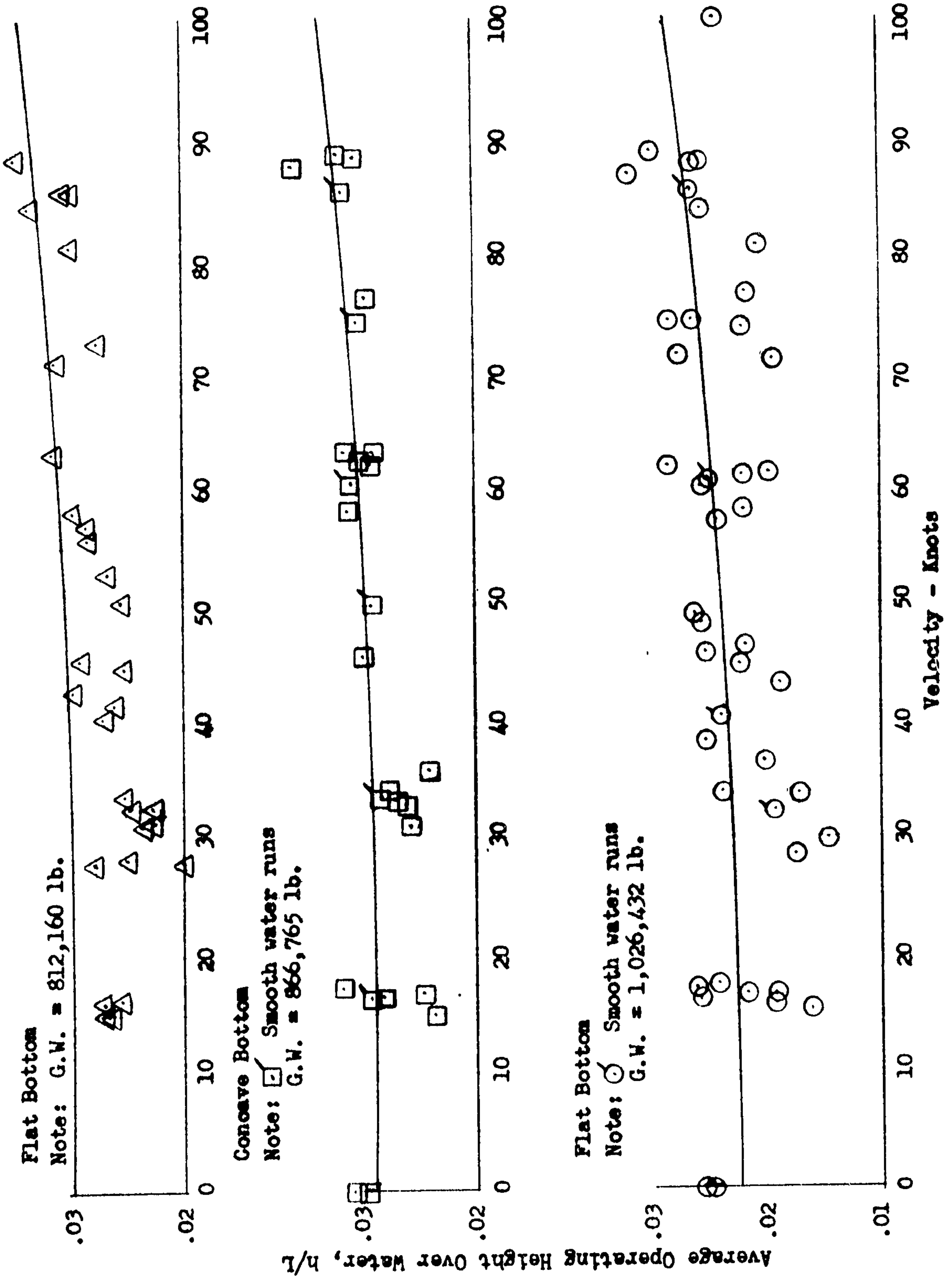
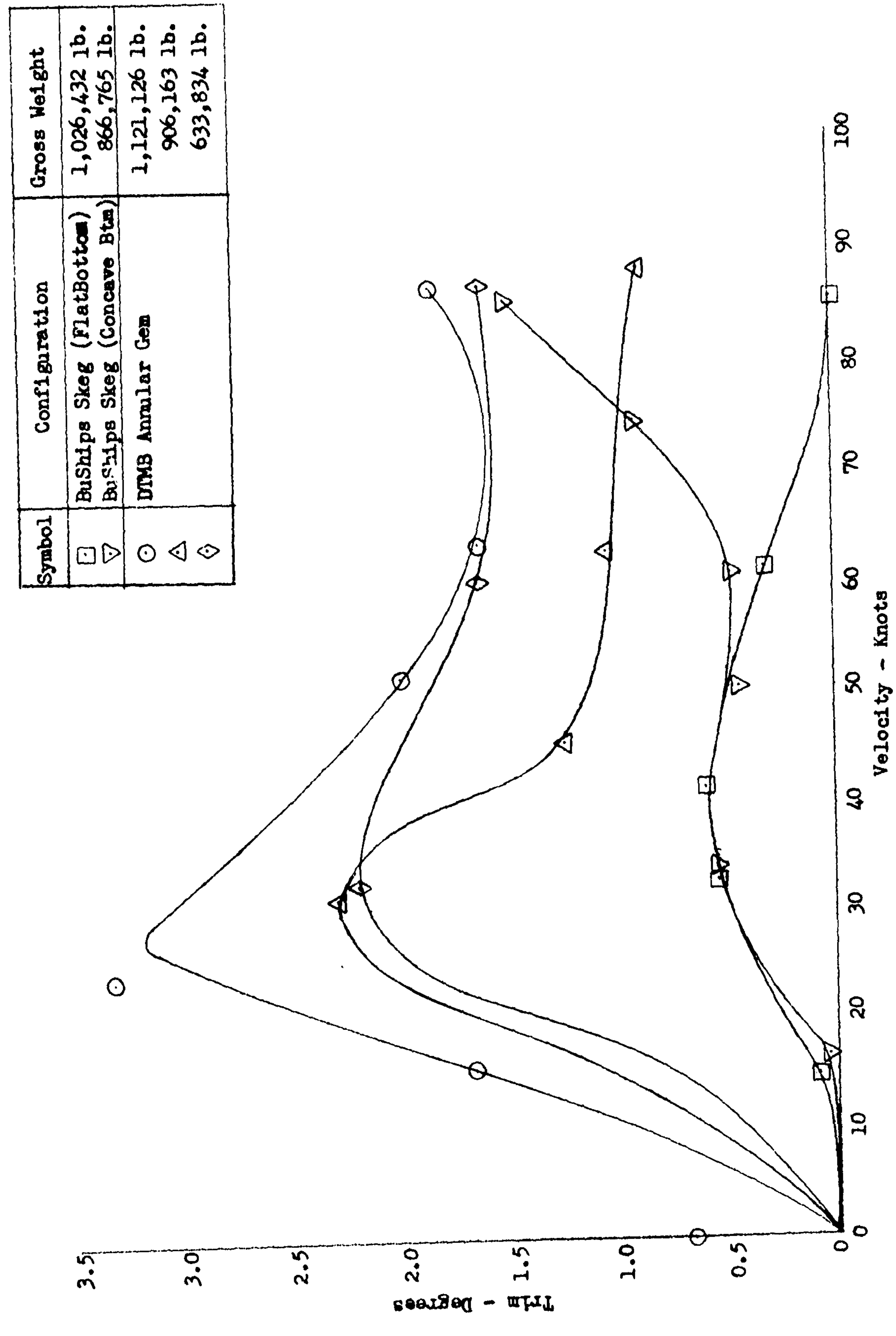


FIG. 25. AVERAGE OPERATING HEIGHT FOR BUSHIPS SKEG GEM
(Continued)



Symbol	Configuration	Gross Weight
□	BuShips Skeg (FlatBottom)	1,026,432 lb.
▽	BuShips Skeg (Concave Btm)	866,765 lb.
⊙	DTMB Annular Gem	1,121,126 lb.
◁		906,163 lb.
◇		633,834 lb.

FIG. 26. SMOOTH WATER CHARACTERISTICS

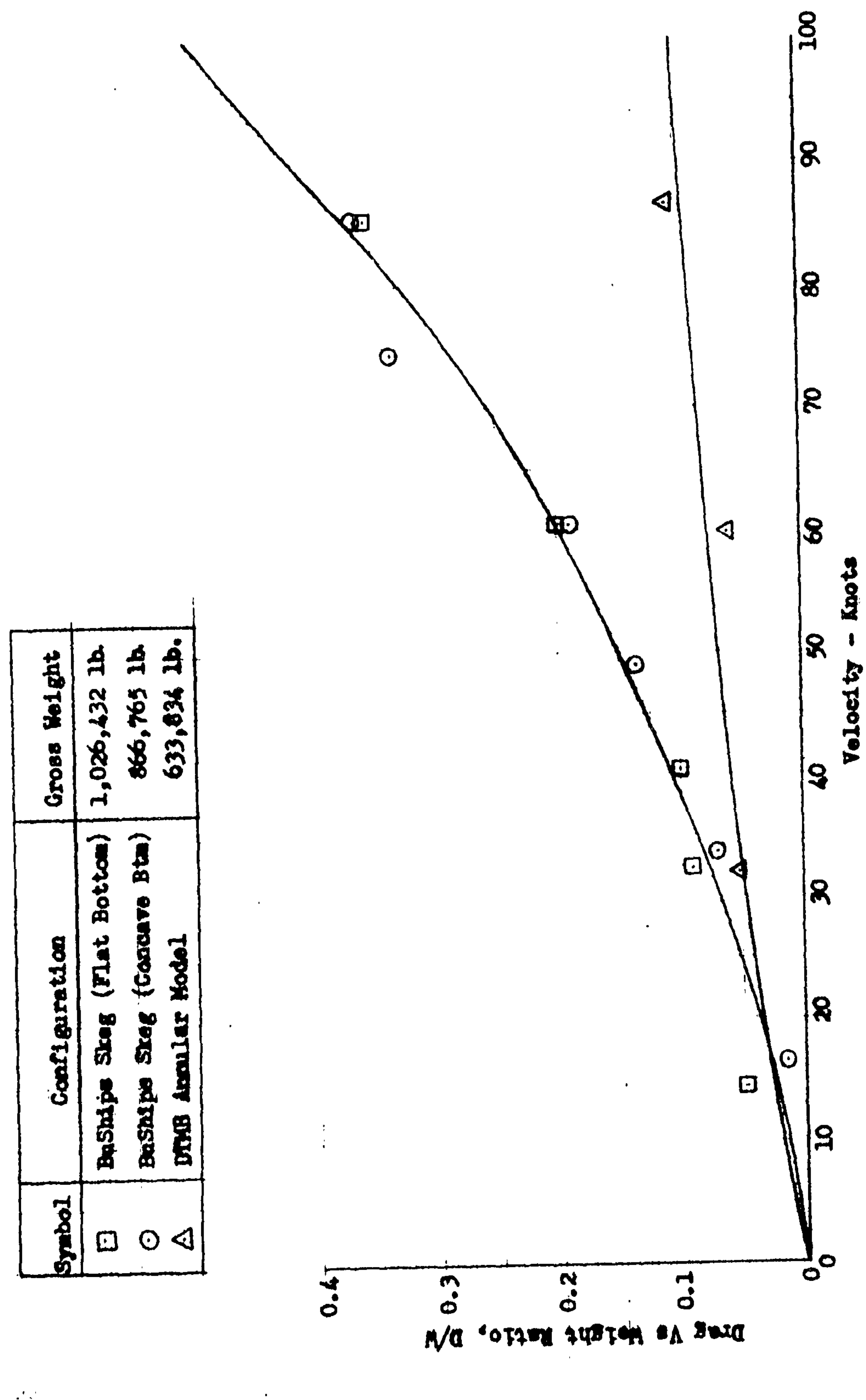


FIG. 27. DRAG VERSUS SPEED (Smooth Water)

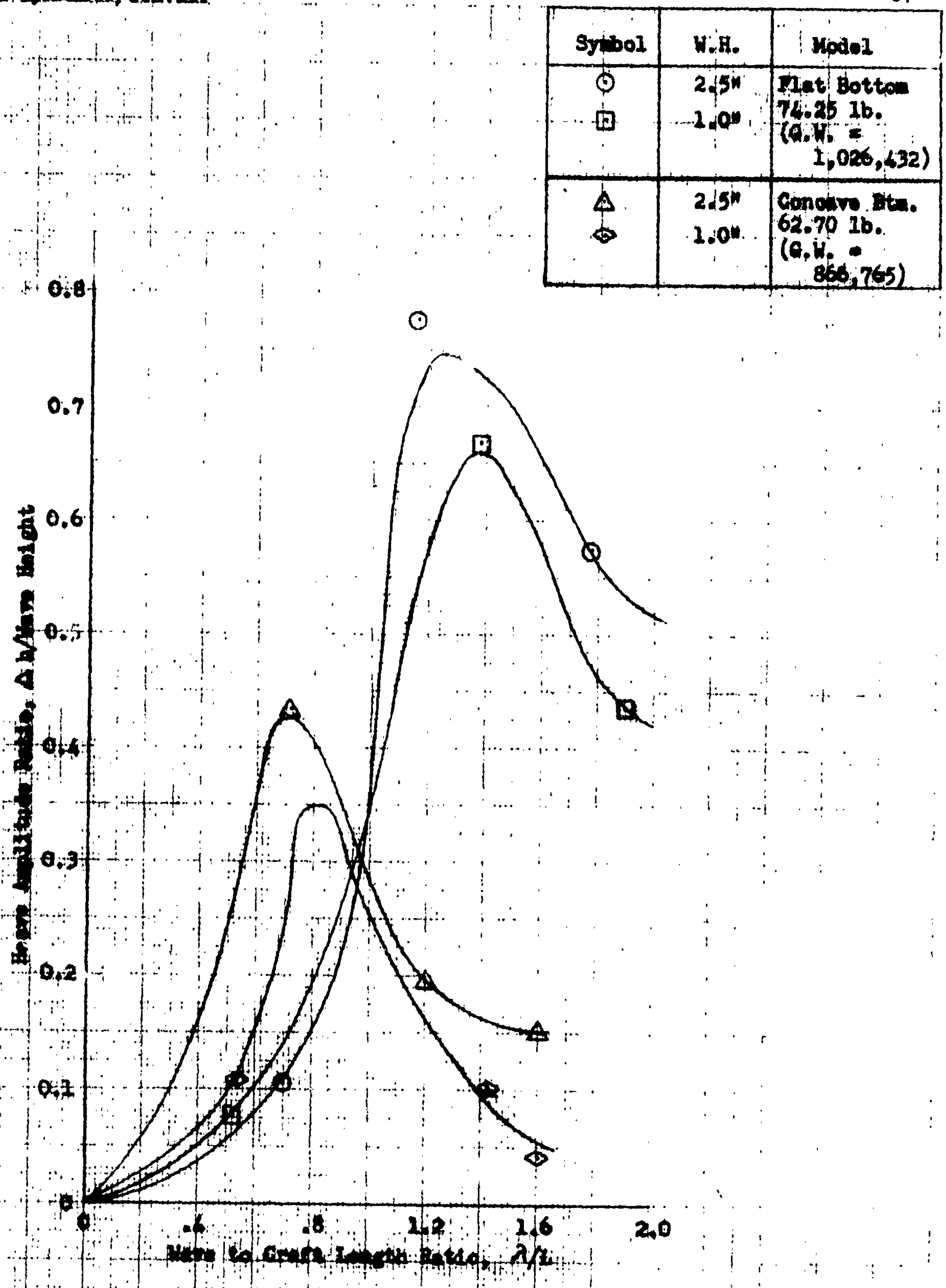


FIG. 28. FLOATING CHARACTERISTICS
BUSHIPS SKEG MODEL

Symbol	W. H.	Model
⊙	2.5"	Flat Bottom 74.25 lb. (G.W. = 1,026,432)
⊡	1.0"	
△	2.5"	Concave Btm. 62.70 lb. (G.W. = 866,765)
◇	1.0"	

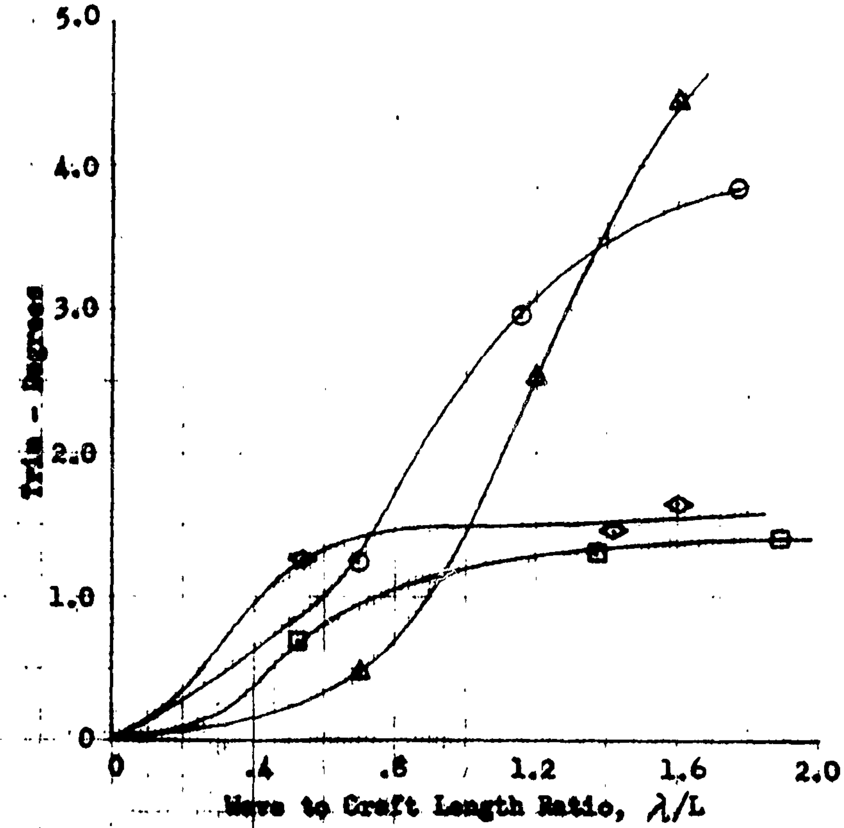


FIG. 29. FLOATING CHARACTERISTICS BUSHIPS SKEG MODEL